THE DEVELOPMENT OF A FIRE SAFETY MANAGEMENT SYSTEM MODEL

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Declaration

Except where reference is made to the work of others, this thesis is believed to be original and has not been submitted for any other degree.

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Abstract

Traditionally, both academe and practitioners have tended to address safety by focusing on technical aspects and looking for the immediate causes of incidents or accidents after they have taken place. More recently, organisations have focused on assessing pro-actively the consequences of the risk inherent in their operations. However, safety still tends to be addressed in isolation, though loss is an emergent property of a system. An organisation's emergent properties result from the interrelated activities of people who design it, manage it and operate it. Although the concepts in this research are general the focus has been on fire safety as an illustration. Because of the need to understand the systemic nature of fire safety, this research project has addressed the problem of what an organisation needs to do so that fire risk can be maintained within an acceptable range throughout the life cycle of the organisation's operations. A fire safety management system (FSMS) model has been developed in an attempt to address the research problem. It is hoped that this approach will lead not only to more effective management of fire safety, but also to more effective management of safety, health and the environment for any organisation. The contribution of this research project is not only to the existing understanding of fire safety, but also to health, safety and the environment. The research process was threefold. First, a thorough review of existing literature on health, safety and environment and systems thinking was conducted. This process helped to establish the FSMS model. Second, the FSMS model was compared with some existing safety management systems, and the case study of Britain's railway safety management was assessed to further explore the FSMS model. Finally, conclusions and implications of the research project have been drawn.

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Chapter One

Introduction

1.1 Background to the Research Project

Safety, health and the environment (SH&E) have become important issues for organisations over the last few years[1,2,3]. Because of several major disasters, such as Flixborough (UK, 1974), Three Mile Island (USA, 1979), San Juanico (Mexico City, 1984), Bhopal (India, 1984), the fire at the Manchester Airport (UK, 1985), the Challenger spacecraft explosion (USA, 1986), Chernobyl (Ukraine, 1987), the King's Cross fire (UK, 1987), the Piper Alpha fire (UK, 1988) and the more recent world - wide railway accidents and aircraft accidents have all highlighted the need to improve radically the safety performance of organisations. Several inquiries and studies have found that technical failure, human errors and organisational failure were the main contributors to these events[4,5,6,7]. Moreover, these events have shown clearly that existing SH&E management failed to prevent such incidents. There is a need for organisations to maintain risks within acceptable ranges. This will require organisations to improve radically their SH&E performance.

Safety in general and fire safety in particular have become, in both academe and industry, subjects of increasing importance in recent years. The need to improve the safety performance of organisations is driven not only by recent accidents or disasters, but also by changes in regulation[8,9,10], the emergence of international standards and the increasing pressure from social organisations. Traditionally, safety approaches have been prescriptive rather than proactive. Safety approaches have focused on performance failures that immediately preceded an accident[7,11,12]. These kinds of failures may involve direct human errors or factors having an immediate impact on the integrity of a system[11,12], or organisation. This way of addressing safety allows the immediate causes which led to the failure to be learnt so that they are not repeated in future situations. Moreover, these negative outcomes are usually seen as a means to measure the organisation's safety and fire safety performance.

More recently, researchers have stressed that the human factor is one of the keys to major disasters[13,14]. Furthermore, an understanding of organisational factors has been a focus to reduce the frequency of major accidents or disasters[11,12,15,16,17,18]. Organisational failures are frequently committed in design, management, communication, and deficiencies in the structure of the organisation[11,12,16,17,19,20]. Addressing organisational failures is as important as focusing on immediate causes of accidents. Despite these significant changes in approaching safety in the oil and gas organisations, significant reduction of accident rates is still a far-reaching objective[21,22,23]. Detailed aspects of the traditional way of addressing safety and fire safety are given in section 1.3.

Oil and gas organisations have shifted from a prescriptive approach to a goal-setting approach to safety[8,9,24]. This new perspective involves assessing the consequences of the fire risks inherent in the organisation's operations before they are actually realised. Quantified Risk Assessment (QRA) is usually used to identify the main contributors to the risk, estimate risk levels and assess their significance, and devise actions to reduce or avoid them[25]. However, fire safety still tends to be analysed in isolation[26,27,28,29]. The organisation as a whole, rather than isolated parts, has become a matter for concern. Approaches to safety seem to pay very little attention to the overall system or organisation[15,30,31]. Very often fire safety approaches address an individual subsystem's performance, rather than assessing the interactions among the subsystems, and their impact on the system's overall performance. In general, a fire loss does not belong exclusively to either technical or human factors, but it is a product of the interactions among the parts that constitute the organisation as a whole; it is a systemic failure. Fire safety may be difficult to assess, particularly in complex organisations, where subsystems' actions and the aggregated activities of the organisation influence each other's behaviour. There is a need to adopt a *systemic* approach to fire safety. Systemic means to look upon events as products of systems. System is understood as an interaction of a number of entities called parts of the system[32] or organisation. The emphasis is to understand particularly the interactions of the organisation's parts, and the impacts of these interactions on the failure propensity of the organisation as a whole. Moreover, the structure of the organisation and the relationships amongst the parts should be clearly understood, as well as the purpose served by this organisational structure. An effective organisation and a structure which may help to make an organisation acceptably safe is needed.

1.2 The Research Problem and Questions

This research project has addressed the following research problem:

What does an organisation need to do to anticipate fire risks so that fire risk can be maintained within an acceptable range throughout the organisation's operations life cycle?

This research project contends that a systemic approach has had to be adopted to address fire safety in a coherent way. Moreover, this systemic approach is intended to help to maintain fire risk within an acceptable range throughout the life cycle of an organisation's operations. Detailed aspects of this approach are given in section 1.4 and in chapter 5.

The research problem has been addressed by developing some research questions. The research questions below needed to be answered throughout the research project.

- ***What is a Fire Safety Management System?***
- ***What defines an effective Fire Safety Management System so that it is capable of maintaining the operational safety of an organisation within an acceptable range?***
- ***How can the fire safety performance of the Fire Safety Management System be measured?***

The research problem and research questions helped to give focus and direction to the research process. The research problem involved decisions on the focus and direction of the research process. The research questions also facilitated a focus on specific information to solve the research problem satisfactorily. The research questions were developed during the literature review of the research process. They are discussed in section 2.2 of chapter 2.

1.3 Motivation for the Research Project

Motivation for this research project was based first on the importance of fire safety in the context of SH&E. Second, the need for an approach that may help to address fire safety as a coherent whole was considered. Third, the significance of the research methodology in constructing a system so that fire risk can be addressed effectively and maintained within an acceptable range was emphasised. Finally, the usefulness of a practical and potential application of the Fire Safety Management System to addressing not only fire safety, but also SH&E was highlighted. These four criteria which are intended to justify this research project are discussed in some detail in the subsequent subsections.

1.3.1 Fire Safety in the Context of SH&E

Traditionally, risks and environmental impacts have been addressed through complying with regulations and relying on 'end-of-pipe' technologies[33]. 'End-of-pipe' involves cleaning up waste after it has been generated. Relatively little has been done previously in the SH&E policies of organisations to reduce risks and prevent pollution. Because of an increasing pressure on organisations resulting from recent accidents or disasters, government legislation, the general public, environmental organisations, commercial institutions etc, have apparently developed a growing recognition of their responsibilities to address SH&E.

As a consequence of these driving forces, safety has become important. Fire is probably one of the greatest hazards that can be encountered in any industrial plant. This is clearly seen in fire disasters, such as the Piper Alpha fire (UK, 1988), and many others world-wide. These kinds of events can contribute not only to loss of property, but also human life and negative impacts on the environment[34,35]. Furthermore, such accidents have had negative economic implications for the organisations concerned[34,36,37,38,39]. Thus fire safety has become a subject of increasing importance[40,41] over recent years. The need to improve the fire safety performance of organisations is driven not only by recent fire accidents and their economic implications, but also by legislation, international standards, and pressures from social organisations.

Organisations have been driven to address safety in general and fire safety in particular by changes in health, safety, and environmental regulation, which have been initiated since the 1970s[8,9,33]. In the oil and gas industry, for example, major changes were emphasised by the Cullen report[24] into the Piper Alpha fire. Examples of recent legislation that addresses the recommendations made by the Cullen report include the offshore installation Safety Case[42] regulations, and the Prevention of Fire and Explosion, and Emergency Response (PFEER)[43,44] regulations. The Safety Case regulations require organisations to demonstrate that the offshore installation's operations are acceptably safe. The PFEER regulations involve the prevention of fires and explosions, as well as all aspects of emergency response, including evacuation, escape, and rescue. Moreover, oil and gas organisations have to address safety throughout the offshore installation's life cycle, as well as safety management systems. These safety requirements are described in the Offshore Installations and Wells (Design and Construction) (DCR)[45] regulations and the Offshore Installations and Pipeline Works (Management and Administration) (MAR)[46] regulations. The DCR regulations emphasise the need for appropriate design, commissioning, operation, maintenance, and abandonment of the offshore installation. The MAR on the other hand emphasise the need for more effective management systems including weather data.

Existing and emerging health and safety regulations are part of a large legal framework. In the United Kingdom, the Health and Safety of Work Act (1974) established the Health and Safety Commission (HSC), as well as setting up the Health and Safety Executive (HSE) to propose health and safety regulations, approve codes of practice, and enforce these regulations. The Act is the primary legislation in the UK under which most subsequent health and safety regulations have been formulated and proposed. For example, the Nuclear Installations Inspectorate, as part of the HSE, is responsible for the particular formulation and application of general safety requirements for the nuclear industry[47]. More recently, three new regulations have been brought into force in the transport industry. These regulations are the Railways (Safety Case) Regulations[48], the Railways (Safety Critical Work) Regulations[49], and the Carriage of Dangerous Goods by Rail Regulations[50]. The railway safety case regulation requires organisations to include the system boundary and technical description, hazard identification, risk assessment, safety management system, and "summing up" statement of safety. The Construction

(Design and Management) Regulations[51] address health and safety management on an obligatory basis for planning and design of construction work.

Similarly, the European Community (EC) legislative framework under the Seveso Directive[35,52] establishes objectives and basic principles with which each member state must comply. Each member state translates them into its own national legislation and the commission and the member's competent authority, such as the HSE, constantly monitors the implementation process towards a substantial convergence. In the United States of America (USA), there has been a rise in the number of health, safety and environmental regulations under the Clean Air Act. Under this law, the Congress specifically directed the Occupational Safety and Health Administration (OSHA)[53] and Environmental Protection Agency (EPA) to develop regulations to prevent future process incidents. The OSHA 1910.119, Process Safety Management of Highly Hazardous Chemicals is the first regulation developed and proposed by the OSHA. The purpose of the OSHA 1910.119 regulation is to prevent catastrophic events that have negative impacts on employees or public health and safety.

Traditionally, quality assurance is a prerequisite in product development and an integral part of production processes. Several international standards have been adopted by organisations to comply with quality requirements. Examples of these standards include International Standard Organisation (ISO) 9000[54] series, and the British Standard 5750[55], and 7850[56]. These standards have an increasing influence on health, safety and the environment. Apart from complying with regulations, organisations face the need to satisfy international standards concerned with safety, such as the ISO 14000[57] series, the British Standard 8800[58] and 7750[59], the European Environmental Management and Auditing Schemes (EMAS)[60], and the American Petroleum Institute (AP1), recommended practice 750[61] and 75[62].

1.3.2 The Need for a Systemic Approach

Recent fire accidents have not only illustrated that fire risk can contribute to loss of property, human life and negative impacts to the environment, but they have demonstrated the inadequacy of the existing fire safety approaches. This is because a series (chain) of unacceptable circumstances has made potential fire risk actual[63]. Traditionally, fire safety approaches have been reactive rather than proactive. They have focused on technical aspects and look for the immediate causes of fire incidents or accidents after they have taken place. This has allowed the immediate causes, which led to the failure, to be learnt so that they are not repeated in future situations. Moreover, these negative outcomes are usually seen as a means to measure the organisation's fire safety performance, such as the Lost Time Injury (LTI)[64].

Fire safety has, however, received increased attention over the last few years as a consequence of recent fire accidents, and changes in regulation, as well as the emergence of international standards. As a result of this, oil and gas organisations have shifted from a reactive approach to a goal-setting approach to fire safety[8,9,21,24]. This new perspective involves assessing the consequences of the fire risks inherent in the organisation's operations before an incident or accident takes place. Under the prescriptive approach, regulations explain how to achieve safety, whilst the goal-setting approach explains what organisations must achieve. A typical goal-setting approach recognises that safety is better assessed and managed by addressing in advance the hazards of the organisation's operations. This is usually done through three basic steps[65,66]: first, a systematic identification of hazards; second, Quantified Risk Assessment (QRA) is usually used to assess the significance of the identified hazards; finally, hazards are managed by prevention, control, and mitigation.

Safety approaches have emphasised performance failures which immediately preceded an accident[7,11,12]. These kinds of failures have been termed "active failures", which are understood as human errors or violations having an immediate impact on the integrity of a system[7,12] or organisation. Researchers have found that the human factor is one of the keys to major disasters[13,14,67,68,69,70]. More recently, however, an understanding of organisational errors has been the focus to reduce the frequency of major accidents or disasters[6,7,12,15,16,17,18,71]. Organisational errors have been termed 'latent failures'[7,12,17,18]. These failures are frequently committed in design, management, communication, deficiencies in structure of the organisation[7,12,16,17,19,20]. It is clear that addressing organisational failures is as important as focusing on directly human or technical causes of accidents. This is clearly seen in recent incidents as a result of the lack of an adequate safety management system[72,73,74,75].

A fire incident or accident is a result of several interrelated factors in the organisation. These fire safety concerns may represent more than a series of individual problems with individual and independent solutions. Moreover, these fire safety deficiencies are highly interrelated and not isolated human aspects or technical aspects. Therefore, there is a need for systemic solutions and not just specific solutions to individual problems. To treat fire safety factors in isolation will ultimately fail to improve fundamentally the safety performance of an organisation's operations.

Very little attention has been given by both academe and practitioners to understanding the appropriate degree of interdependence amongst the parts that constitute an organisation in order to design an effective safety management system (SMS). Vaughan[5] emphasises that the relationships amongst the parts of an organisation and the interaction of the organisation with other organisations are characterised by "structurally engendered weaknesses" that contribute to technical failures. Moreover, the author stresses that this is a result of the sophisticated formulae used to estimate risk in technical systems which do not consider the possible organisational contribution to these failures. According to Vaughan, risks are always underestimated creating unwarranted confidence in all risky technological systems. Segan[76] discusses high reliability organisations in order to understand the origin of accidents. Segan argues that:

"High reliability theorists believe that hazardous technologies can be safely controlled by complex organisations if wise design and management techniques followed. This optimistic conclusion is based on the argument that effective organisations can meet the following four specific conditions, which are necessary to create and maintain adequate safety:

- *political elite and organisation leaders place a high priority on safety and reliability;*
- *significant levels of redundancy exist, permitting backup or overlapping units to compensate for failures;*
- *error rates are reduced through decentralisation of authority, strong organisational culture, and continuous operations and training; and*
- *organisational learning takes place through a trial-and-error process, supplemented by anticipation and simulation."*

Perrow[15] discusses an alternative approach, known as normal accident theory, in order to understand the underlying causes of accidents. The normal accident theory contends that:

- organisations and their members or parts are self-interested actors with potentially conflicting interests, and the organisations are strongly influenced by the broader socio-economic context or environment;

- interactive complexity within the organisation makes it difficult to understand and so makes it prone to failures;
- there exists conflicting interests amongst the organisation's parts and between the organisation and its environment; and
- whether the organisation or system is "tightly coupled" or "loosely coupled" affects its ability to recover from small-scale failures before these cascade into larger problems.

It is recognised in the normal accident theory that serious accidents are inevitable if the organisation that controls hazardous technologies displays both high interactive complexity and 'tight coupling'.

Grabowski and Roberts[12] stress that the structure of an organisation has a significant impact on the organisation's safety culture, communication, and decision making. According to them, the organisational structure of a SMS should allow decisions to be made at the local level. This means that decision making should be distributed throughout the whole organisation. These decision makers should be autonomous in their own right and act independently based on their own understanding of fire safety and their specific tasks. However, it should be recognised that they have interdependence with other decision makers from other operations of the organisation. Therefore, each operation should be endowed with a degree of autonomy so that the organisation's fire safety policy can be achieved more effectively. These aspects of organisational structure, which have a role in making organisations more rather than less effective, are poorly understood in safety and fire safety literature.

It has long been known that an organisation's communication system has a significant impact on the organisation's performance. Also, it has been discussed elsewhere[12] that distributed decision making is impossible without communication. Good decision making relies on well-designed networks of 'real-time' information systems. Moreover, a good communication system may serve as a means to divulge and sustain an organisation's safety culture. A typical problem associated with poor communication is lack of trust[77,78,79], and trust within organisations is a continuous process[80]. An organisational structure needs to be in place to ensure that this process of trust is sustained throughout the organisation's life cycle. Organisations that require constant attention to safety should be characterised by a well-designed organisational structure and strong safety culture. There is therefore a need to address the structure of an SMS that may help organisations to reduce problems associated with communication, human and organisational factors.

1.3.3 The Significance of the Research Methodology

A research methodology that gave direction and consistency to the research project was adopted. This research methodology is described in section 1.4. The research activities were structured into three phases, namely theory, practice, and reflection. In the theory phase, existing literature on SH&E, fire safety, and systemic thinking was studied to construct a Fire Safety Management System (FSMS) prototype. A typical oil and gas organisation was used to construct a prototypical FSMS, though the approach is intended to be general. In the practice phase, the developed FSMS prototype is initially tested through a series of mappings to systemic paradigms, such as communication and control and human aspects. Experiences learnt from this mapping process were integrated into the FSMS prototype to produce an FSMS model. The FSMS model was then mapped on to some existing safety management systems. The FSMS model is further elucidated through a probabilistic computer simulation. Finally, in the reflection phase, the researcher reflected on the research process itself. The resulting experience from the research process helped to consolidate contributions of the research project and outline recommendations for further research.

1.3.4 Potential Applications of the FSMS Model

The FSMS model developed and proposed in this research project is a systemic approach intended to maintain fire risk within an acceptable range in an organisation's operations in a coherent way. It is hoped that this systemic approach will lead not only to more effective management of fire safety, but also to more effective management of safety, health and the environment for any organisation. This research project also established the concept of viability of the FSMS model in quantitative terms.

1.4 The Research Methodology

A three phase research methodology was used throughout the research process in order to accomplish the research project, as illustrated in Table 1.1.

Table 1.1 The Research Methodology Phases and Activities

Research Phases	Research Activities	Research Phases Output
Theory	1. literature review on SH&E, safety, and fire safety 2. literature review on systemic thinking 3. construct a FSMS prototype	1. an FSMS prototype
Practice	4. map FSMS prototype to some systemic paradigms of the Failure Paradigm Method (FPM) 5. FSMS mapped on to existing Safety Management Systems 6. Case study: assessing the British railway safety management	2. synthesis: a FSMS Model 3. lessons from further testing
Reflection	7. reflect upon research process	4. conclusions and implications

1.4.1 Theory Phase of the Research Methodology

In the theory phase of the research methodology three main activities were conducted.

Literature Review on SH&E and Fire Safety

A continuous review of existing literature on SH&E and fire safety was conducted throughout the research project. This activity involved analysing published literature from both academe and practitioners' perspectives', as well as visiting practitioners to discuss fire safety issues. An understanding of the nature of fire safety from different perspectives was gained through this activity. Thus, this activity facilitated the establishment and formulation of the research problem and questions. Relevant literature to this research project is presented in chapter 2.

Reviewing the Literature on Systemic Thinking

This second activity of the research process involved studying systemic thinking principles, as well as studying systemic approaches. This activity also involved both studying existing literature on systemic thinking and existing approaches to systems, and gaining practical understanding from practitioners. The Viable System Model (VSM)[81,82,83,84] and the Failure Paradigm Method (FPM)[85,86] were adopted and studied in some detail to address the research problem and questions. These two approaches to systems are described in some detail in chapter 3. The next subsections describe how they were used to develop a FSMS model, which is presented in chapter 5.

Constructing the FSMS Prototype

This last activity of the theory phase involved constructing an FSMS prototype. The approach taken to formulate the prototypical FSMS builds on the Viable System Model (VSM) developed and proposed by Beer[81,82,83,84]. A Viable System is defined by Beer[82] as that which is able to maintain a separate existence. Very few, if any, systems would fulfil this definition and in this research project a viable system has been regarded as one which is able to maintain a relatively separate existence. This has been further interpreted as a system which is able to remain stable, or resilient, and continue to be able to fulfil its purpose. Beer contends that in any viable system there are five necessary and sufficient subsystems interactively involved in any organism or organisation that is capable of maintaining its identity independently of other such organisms within a shared environment. A FSMS prototype resulted from this activity of the research methodology. Detailed aspects of the FSMS prototype are discussed in chapter 4.

1.4.2 Practice Phase of the Research Methodology

Three main activities were accomplished in the practice phase of the research methodology and are discussed below.

Testing the Prototypical FSMS

The purpose of the initial test of the developed FSMS prototype was to identify its weaknesses and strengths. To accomplish this objective, the FPM, proposed by Fortune and Peters[85,86], was mapped on to the FSMS prototype. The VSM facilitated an understanding to formulate the FSMS organisational structure. The FPM, *inter alia*, provided some best practices that helped the understanding of some human aspects. The strengths and weaknesses of the FSMS prototype are discussed in chapter 4. This initial testing of the FSMS prototype led to a synthesis: that is, an FSMS model. This model is presented in chapter five.

Synthesis: a FSMS Model

The FSMS model developed in this research project is a systemic set of five inter-related subsystems, as shown in Figure 1.1. The FSMS needs to achieve five functions associated with systems 1 to 5. System 1, *fire safety policy implementation*, implements the organisation's fire safety policy. System 2, *fire safety co-ordination*, involves co-ordinating the various operations of system 1. System 3, *fire safety functional*, involves ensuring that the organisation's fire safety policy is implemented, as well as ensuring that the fire safety is maintained within an acceptable range. System 3*, *fire safety audit*, conducts sporadic audits into the operations of system 1. System 4, *fire safety development*, is responsible for the future fire safety development for the whole organisation. System 4*, *fire safety confidential reporting,* deals with the organisation's employees confidential fire safety concerns. Finally, system 5, *fire safety policy*, is responsible for establishing fire safety policies for the whole organisation.

The FSMS model developed and presented in this research project integrates both internally committed systems (ICS) and externally committed systems (ECS) (to be defined later in section 5.3.2, chapter 5), into a systemic model that is also intended to quantify an organisation's fire safety performance. This measure of fire safety performance provides decision makers with the means to define fire risk levels and make fire safety plans. Moreover, a notional fire safety configuration space was devised to help to 'diagnose' the fire safety performance of technical and non-technical systems, such as organisations and humans individually, in teams, and in organisations. A detailed description of the FSMS model is presented in chapter 5.

Mapping the FSMS Model on to other SMSs.

This activity involved mapping the FSMS model on to other oil and gas organisation's safety management systems. Two North Sea oil and gas operators provided descriptions of their safety management in the form of 'safety cases' to complete this mapping process. Standard safety management schemes, such as BS 8800[58], etc., were also used to be mapped to the FSMS model. Lessons learnt from this mapping process are discussed in chapter 6.

Further Elucidation of the FSMS Model

The purpose of this activity was to illustrate how the FSMS model can be used in other type of industries in order to assess the existing safety management. This was demonstrated for the case study of the British railway safety management. Results from this case study have been recorded and are presented in chapter 7.

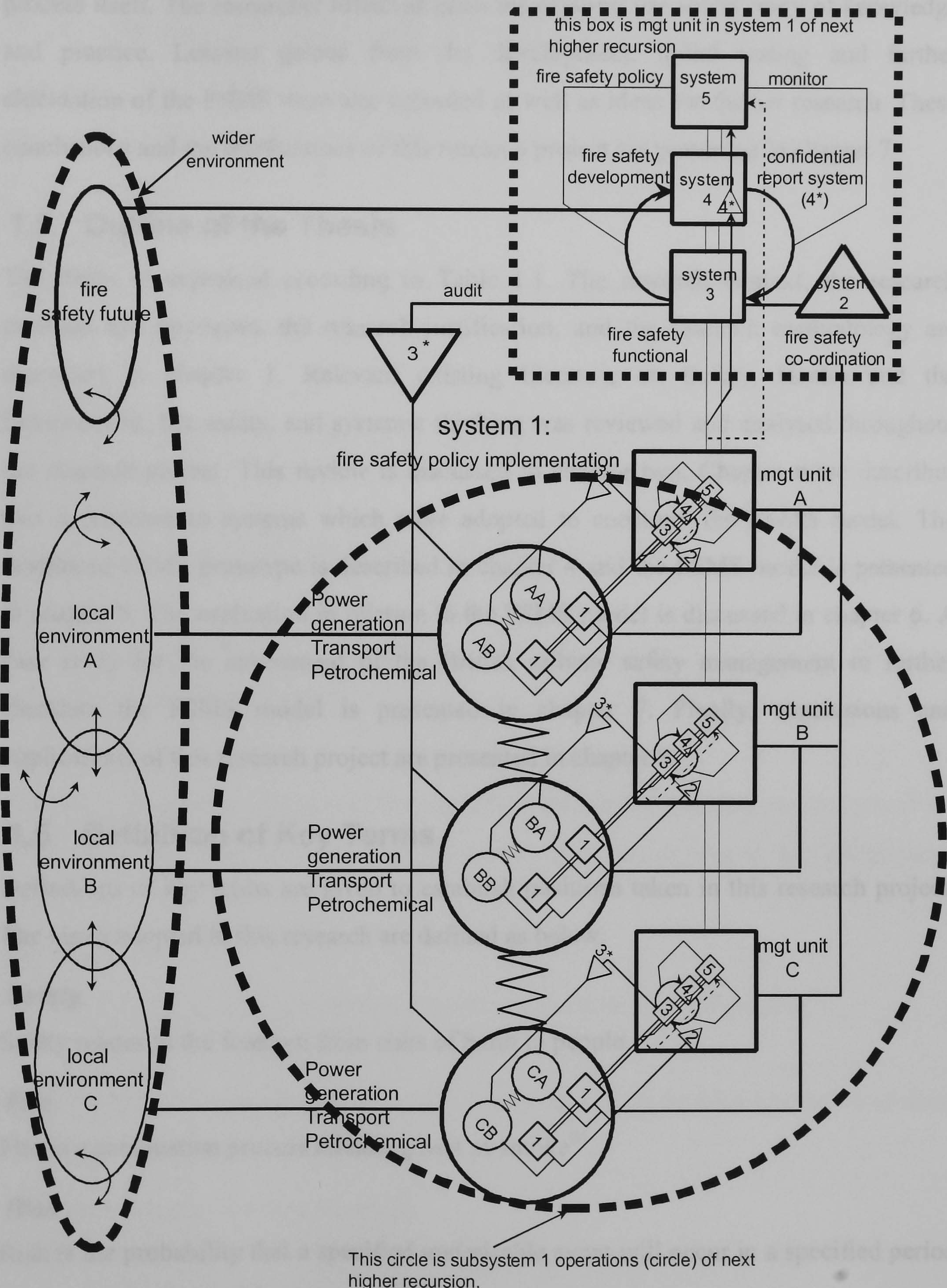


Figure 1.1 A Fire Safety Management System Model

1.4.3 The Reflection Phase of the Research Methodology

In this last phase of the research methodology, the researcher examined the research process itself. The researcher reflected upon the existing fire safety body of knowledge and practice. Lessons gained from the development, initial testing and further elucidation of the FSMS were also recorded as well as ideas for further research. These conclusions and the implications of this research project are presented in chapter 7.

1.5 Outline of the Thesis

The thesis is organised according to Table 1.1. The research context, the research problem and questions, the research justification, and the research methodology are discussed in chapter 1. Relevant existing literature on Safety, Health and the Environment, fire safety, and systemic thinking was reviewed and analysed throughout the research project. This review is discussed in chapter two. Chapter three describes two approaches to systems which were adopted to construct the FSMS model. The developed FSMS prototype is described in chapter 4 and the FSMS model is presented in chapter 5. The evaluation in relation to the FSMS model is discussed in chapter 6. A case study for the assessment of the British railway safety management to further elucidate the FSMS model is presented in chapter 7. Finally, conclusions and implications of this research project are presented in chapter 8.

1.6 Definition of Key Terms

Definitions of key terms are given to establish positions taken in this research project. The terms adopted in this research are defined as below.

Safety

Safety relates to the freedom from risks of harm to people.

Fire

Fire is a combustion process releasing heat or smoke[66].

Risk

Risk is the probability that a specified undesirable event will occur in a specified period or as a result of a specified situation[87].

System

System is understood as an interaction of a number of entities called parts of the system or organisation[32].

Variety

Variety is the number of possible states of a system[83]

Viable

According to Beer, 'viable' means able to maintain a separate existance[83].

In this research , 'viability' has given the specific meaning below.

Autonomy

Autonomy is the freedom of a subsystem to act on its own initiative, but only within the framework of action determined by the purpose of the total system[82].

Recursion

Recursion is a level that contains all the levels below it[82].

Systemic

Sytemic means to looking upon events as products of systems.

Structure

The term structure emphasises the relations among the parts as well as the identity of the parts which constitute a whole[88].

Organisation

The word organisation emphasises the relations which define a system as a unity with no reference to the nature of the components which can be any as long as they satisfy these relations[88].

Paradigm

The word paradigm is used to denote a pattern or example of good practice[85].

The following terms are proposed in this research project. A detailed discussion of these terms is given in chapters five and Six.

Internally Committed System (ICS)

An ICS is a system that is committed to a particular purpose or objective based on its own reasons or motivation.

Externally Committed Systems (ECS)

An ECS is a system that is committed to a particular purpose, function, or objective based on external reasons or motivation.

According to Beer, 'viable' means able to maintain a separate existance[83].

In this research , 'viability' has given the specific meaning below.

Viability

Viability = Probability that the FSMS has the capacity to maintain the risk within an acceptable range, for a stated period of time.

Maximum Risk Acceptable (MRA)

MRA is understood here as the level of fire risk above which the risk is definitely unacceptable.

An Acceptable Range of Fire Risk

An acceptable range of fire risk is one which is below the MRA and, as a general rule, well below the MRA.

Acceptable Level of Fire Risk

An acceptable level of fire risk is one which is within an acceptable range.

Fire Safety Levels

- *current* achievement level (CAL) is the fire risk level an organisation manages with existing resources, and under existing constraints.
- *without significant extra investment* level of achievement (WEIL) can be defined as the fire risk level an organisation could achieve with existing resources and under existing constraints, if resources and technology were better organised.
- *minor extra investment* level of achievement (MINEIL) can be defined as the fire risk level an organisation ought to be achieving, if some minor extra investment is made to eliminate some shortcomings in capacity or technology.
- *major extra investment* level of achievement (MAJEIL) can be defined as the fire safety performance an organisation would be capable of achieving, if a major investment in new equipment, or new technology is made to eliminate current constraints.

Fire Safety Plans

Planning is understood here as being a continuous process of decision-taking, whereby resource allocations are made, so that the future organisation's fire safety performance may be better.

- Planning fire safety from the CAL is referred to here as *operative* fire safety planning.
- Planning fire safety from the WEIL is called *programmatic* planning.
- Planning fire safety from the MINEIL is referred to as *strategic* fire safety planning.
- Planning fire safety from the MAJEIL is termed *normative* planning.

Fire Safety Indices of Achievement

- *The short term index of achievement* (SIA) is given by the ratio of WEIL to the CAL.
- *The medium-term index of achievement* (MIA) is defined by the ratio of MINEIL to the WEIL.
- *The long-term index of achievement* (LIA) is given by the ratio of the MAJEIL to the MINEIL.
- The overall fire safety performance index of an organisation can be obtained either by the ratio of the CAL to the MAJEIL, or by the product of SIA, MIA, and LIA indices.

Fire Safety Configuration Space

The fire safety configuration space is a notional space on to which technical systems, and non-technical systems such as organisations, and humans, individually, in teams, in organisations, can be mapped to assess their fire safety performance.

1.7 Limitations and Assumptions of the Research Project

This research project emphasises the development of a systemic approach to address fire safety in oil and gas offshore operations, though the approach can be easily extended to address SH&E and be made applicable to any organisation. To construct the FSMS, it was assumed that an oil and gas organisation, apart from producing oil and gas, produces an acceptable range of fire risk also. This helped to define the purpose of the FSMS; how this was done is described in chapter 4. It should be emphasised that the various operations that form part of system 1 of the FSMS were defined according to the researcher's own understanding and perception of the situation. However, in a real situation, these operational elements of system 1 must be defined according to the perceptions of the organisation's employees, line management and top management.

1.8 Conclusion

This chapter has presented the foundations for the whole thesis. It first introduced the research problem and research questions. The research project was justified; then the research methodology was described and justified; the outline for the thesis was presented, and key concepts and definitions were presented. The limitations and assumptions of the research project were given. On these foundations, the thesis can continue with a detailed description of the research project.

Chapter Two

Literature Review

2.1 Introduction

Chapter one presented the research context and the research problem, and put forward the research questions. The research project was justified. The research methodology, and the research limitations and assumptions were also discussed. This chapter reviews existing literature on Safety, Health and the Environment (SH&E), and fire safety in the context of the research problem. The discussion presented in this chapter is structured according to the research problem and questions, as shown in Figure 2.1. Section 2.2 discusses a definition of a safety and fire safety management system, as well as discussing systemic thinking principles. It also formulates some research questions. Section 2.3 reviews existing literature on SH&E Management Systems. Existing specific tools and methods to address safety and fire safety are discussed in section 2.4. Section 2.5 summarises the lessons learnt from the review process. Finally, section 2.6 concludes chapter two.

2.2 Safety and Fire Safety Management

Managing the risks associated with an organisation's operations has been a subject of increasing importance over recent years. However, very little emphasis has been given in both academe and industry to define what constitutes either a safety management system (SMS), or an effective SMS. There are still no well defined and accepted criteria that may help to establish an effective SMS. George[89] describes key functions of management, namely planning, organising, commanding, co-ordinating, and controlling which are linked to form a closed loop. Similarly, Druker[90] contends that management involves setting objectives, organising, communicating, establishing yardsticks, and developing people.

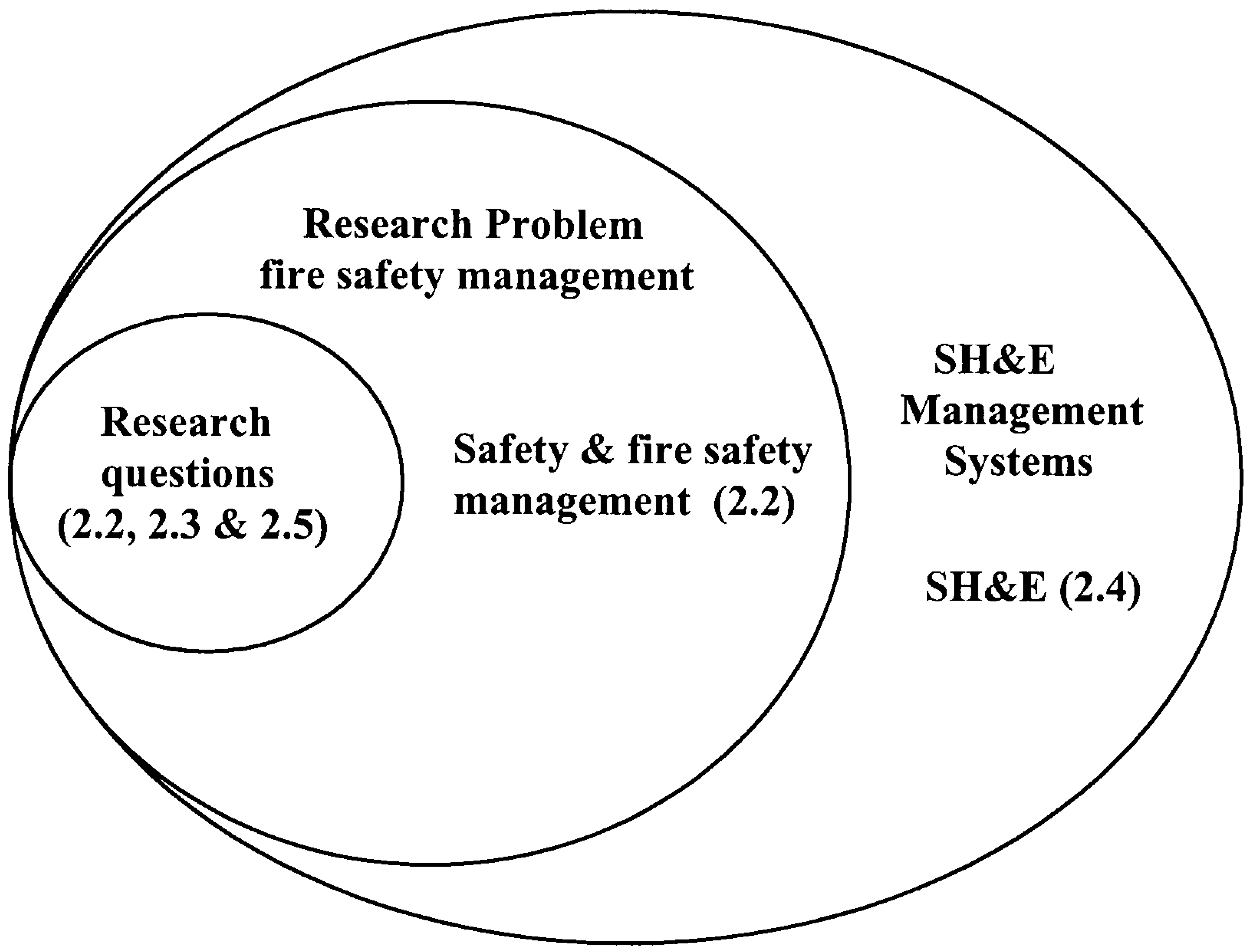


Figure 2.1 The Review Process

Larken[91], contends that

"management is the intelligent and disciplined application of common sense, advice, guidance, judgement and professional knowledge in a properly planned, logical and co-ordinated manner to the solution of relevant problems with due priority, allied to the resources and communications necessary to resolve them, normally, if not always within a framework of objectives set by senior management".

In the oil and gas industry, for example, the Offshore Installation (Safety Case) regulations[42] emphasise that the term 'management system' means

"the organisation and arrangements established by the duty holder for managing his undertaking".

Furthermore, the Safety Case Regulations emphasise that those elements concerned with safety performance are referred to collectively as the SMS. Roughton[92] integrates the principles of total quality management (TQM) with safety. TQM is understood as trying to succeed by continually improving a product or service, whilst quality can be defined as the conformance to requirements, with requirements being defined by designers.

Roughton further stresses that the concept of prevention should be adopted, since injuries to workers and to the environment represent an unacceptable waste of resources. Pappas[93] stresses that a SMS should ensure that safety requirements of regulatory agencies are complied with. He further emphasises that a SMS has two different aspects: first, to provide a basis for decisions within the line organisation regarding safety; second, to follow up and verify the implementation of the decisions. In a paper presented by Ming[94], a SMS is defined as the policies, objectives, organisation, management controls and resources which are in place to manage SH&E in all parts of the business. Whittingham and Hollywell[95] argue that the SMS and the organisation's safety culture should be considered together. They also argue that an effective SMS needs to be a more formalised version of existing management systems for the control of both safety and production. Moreover, effective safety management results from the combination of a SMS structure and the organisation's safety culture.

More recently, Burkhardt[96] defines process safety management (PSM) as:

"*the application of management systems to the identification, understanding, and control of process hazards to prevent process-related injuries and incidents*".

Similarly, the British Standard Institute (BSI)[58] defines a management system as

"*a composite, at any level of complexity, of personnel, resources, policies & procedures, the components of which interact in an organised way to ensure a given task is performed, or to achieve or maintain a specified outcome*".

The BSI also defines organisation as

"*a company, operation, firms, enterprise, institution, or association, or part thereof, whether incorporated or not, public or private, that has its own functions & administration. For organisations with more than one operating unit, a single operating unit may be defined as an organisation*".

Moreover, the BSI emphasises that the elements of Occupational Health and Safety (OH&S), based on the BS EN ISO 14001 management system, are all essential for an effective OH&S management system. The key elements of the OH&S management system are OHS policy, planning, implementation and operation, checking and corrective action, and management review.

Other authors such as Travers[97] contend that the Successful Health and Safety Management (HS(G)65), developed by the Health and Safety Executive (HSE), provides the basic criteria for an effective management system. The HS(G) 65 management system involves policy, organising, planning and implementing, measuring performance, reviewing performance, and auditing. A study conducted by Kandola[98] contends that

"*a management system must enable the assessment of risks to be carried out and as a result devise and implement adequate risk reduction measures and provide appropriate feedback mechanisms for further improvement*".

Kandola further contends that such a safety system must be dynamic and proactive, as well as protecting people, property and the environment. Other researchers, such as Reason[7] contend that

"*an effective safety management means actively navigating the safety space in order to reach and then remain within the zone of maximum resistance*".

Reason emphasises that managers should regularly measure and improve those processes, such as design, hardware, training, procedures, maintenance, planning, budgeting, communication, goal conflicts, and the like. These processes are known to be the sources of organisational failure. Moreover, Reason contends that safety management should not be an add-on, but an essential part of the organisation's core business.

The European Council Directive 96/82/EC[99], known also as SEVESO II, defines a SMS as including

"*the organisational structure, responsibilities, practices, procedures, processes and resources for determining and implementing the major-accident prevention policy*".

Finally, Mitchison and Papadakis[100] contend that safety management is an aspect of the overall management function that determines and implements the organisation's safety policy. This involves a series of activities, initiatives and programmes which focus on technical, human and organisational aspects and refers to all the individual activities within the organisation. Moreover, these activities are associated with the concept of continuous improvement through 'control loops', which involve planning, organising the work, implementing, evaluating, checking the outcome against the plan, and adjusting/taking corrective action. Thus safety management is converted into a formal SMS.

As mentioned above, there remain questions concerning what constitutes and defines an SMS and an effective SMS. The following research questions require to be answered.

What is a Fire Safety Management System?

What defines an effective Fire Safety Management System so that it is capable of maintaining the operational safety of an organisation within an acceptable range?

How can the fire safety performance of the Fire Safety Management System be measured?

In order to answer these questions, the subsequent sections review existing literature on systemic thinking, as well as reviewing existing practices on safety and fire safety management, and safety performance.

2.3 Understanding Organisations

This section explores the key aspects of systemic thinking. It discusses what they are and why they are useful to understanding organisations. It also discusses a systemic approach adopted in this research project to develop an effective FSMS. Systemic thinking is a conceptual framework or body of knowledge and tools that has been developed over the last fifty years[101]. According to Senge[101], systemic thinking is a discipline for seeing wholes. It is a framework for seeing relationships rather than things; for seeing patterns of change rather than static 'snapshots'. Checkland[102] emphasises that systemic thinking is a process of reflection about the real world which uses systems ideas. Systemic thinking is holistic thinking that addresses things in a broader context of the world about them and explores the relationships with this external world, as well as emphasising the interactions within the system itself. For example, an education system is seen as part of society as a whole and not as something to be analysed in isolation from the broader context. The strength of systemic thinking is that it forces the practitioner to gather all possible processes and interrelationships among parts into an organised structure. Ackoff[103] emphasises

"the performance of the whole is not the addition of the performance of the parts, but it is a consequence of the relationship between the performance of the parts. It is how performance relates, not how it occurs independently of the other parts. That is what systems thinking is about".

The key concepts of systemic thinking in contrast with analytical thinking, the two being complementary of scientific thinking, are boundary, emergence, and hierarchy. These three key ideas of systems thinking are described before proceeding to discuss a systems approach, which can then be described not only as systematic, but, more importantly, systemic.

Boundary and Emergence

It is generally recognised in systemic thinking that the notions of scientific method are reductionism, repeatability and refutation[104]. Reductionistic methods of analysis consider situations within carefully set boundaries, which are assumed to isolate them from external influences or at least to circumscribe such external influences to create a set of well-defined inputs and outputs. The distinction between reductionistic and systemic methods of analysis is important to the argument behind this research project. Reductionistic methods of analysis may seem intrinsically flawed. Simplicity is one considerable advantage of reductionistic analysis but isolating events can give an over-simple understanding of them. This may be insufficient to understand complex and unforeseen situations. The application of reductionistic methods of analysis has rendered science unable to explain complex situations. For example, the science of physics and chemistry cannot explain complex biological processes. Although biology draws extensively on scientific methods to explain biological processes, it demonstrates the emergence of behaviour, which is inexplicable in terms of the processes with which physics and chemistry are concerned. As Jacob[105] contends:

"At each level of organisation novelties appear in both properties and logic. To produce is not within the power of any single molecule by itself. This faculty appears only with the simplest integron deserving to be called a living organism, that is the cell. But thereafter the rules of the game change. At the higher level integron, the cell population, natural selection imposes new constraints and offers new possibilities. In this way and without ceasing to obey the principles that govern inanimate systems, living systems become subject to phenomena that have no meaning at the lower level. Biology can neither be reduced to physics nor do without it. Every object that biology studies is a system of systems. Being part of a higher order system, it itself obeys rules that cannot be deduced simply by analysing it. This means that each level of organisation must be considered with reference to adjacent levels... At every level of integration, some new characteristics come to light... Very often, concepts and techniques that apply at one level do not function either above it or below it. The various levels of biological organisations are united by the logic proper to

reproduction. They are distinguished by the means of communication, the regulatory circuits and internal logic proper to the system".

In the above quotation, the author recognises the notions of emergence and boundary which relate to levels of organisation, wholes (integrons, molecules, or cellular organelles) and the process of communication and control between wholes arranged hierarchically. Organisations that have to survive in complex markets will need to learn and adapt quickly to changes while satisfying safety and fire safety requirements. Such capability is unlikely to be achieved by designing and analysing parts of the organisation in isolation. This requires the commitment of the organisation as a whole to be adaptive, as well as retaining the cohesion necessary to achieve collective goals.

Emergence and Hierarchy

Checkland[102] expresses the notion of emergence and hierarchy as follows:

"It is the concept of organised complexity which became the subject of the new discipline, 'systems; and the general model of organised complexity is that there exists a hierarchy of levels of organisation, each more complex than the one below, a level being characterised by emergent properties which do not exist at the lower level. Indeed, more than the fact that they 'do not exist' at the lower level, emergent properties are meaningless in the language appropriate to the lower level. 'The shape of an apple', although the result of processes which operate at the level of the cells, organelles, and organic molecules which comprise apple trees, and although, we hope eventually explicable in terms of these processes, has no meaning at the lower levels of description. The processes at these levels result in an outcome which signals the existence of a new stable level of complexity-that of the whole apple itself-which has emergent properties, one of them being the apple's shape".

According to the above, hierarchy is concerned with the fundamental differences between one level of complexity and another. The idea of hierarchy aims to provide both an elucidation of the relationships between different levels and an elucidation of how observed hierarchies come to be formed. Furthermore, hierarchy levels are characterised by processes of control and communication that operate at the interfaces between levels. This elucidates the concept of boundary as discussed below.

Boundary

It is stressed in systemic thinking that systems practitioners can define a whole by simply constructing a boundary, wherein lies the totality of parts. They are free to choose the precise locus of this boundary in a way and according to a particular view, *weltanschauung*, that takes their interest. Boundary specification is a matter for the observer to define.

Defining System

Not long ago the term system was hardly used. However, the idea of systems has gradually gained more and more importance over recent decades. This is reflected in the widespread used of the term 'system'. For example, it is common to hear about the solar system, political and social systems, housing systems, transport and communication systems, biological systems, mechanical systems, ecological systems, etc. These examples are at first sight very different, but they all have one thing in common. They are all assemblies of different parts richly interconnected with each other. Although everyone knows or thinks they know what system means, it is surprisingly difficult to define precisely. The word system is defined below.

A system may be defined as a whole which is made of parts. According to Beer[32], a system is exceedingly complex, highly probabilistic, and at least in certain ways, self-regulating. Furthermore, Beer stresses that there are three aspects in recognising a system. First, particular relationships are acknowledged. This collection of relationships turns into an assemblage of relationships. Second, a pattern in the set of relationships can be detected. This turns an assemblage into a systematically arranged assemblage of relationships. Finally, this arrangement of relationships has a purpose. This is a system. However, it is stressed that coherence, pattern, and purpose are all acts of mental recognition rather than characteristics of physical things. Moreover, Beer contends that knowing the relation correctly is more valuable than knowing correctly which things are related.

The next subsection discusses a systemic approach that has been adopted in this research project to address the research problem. A systemic approach is understood as one which uses the concepts of cybernetics and systemic thinking as a basis for designing systems.

2.3.1 Management Cybernetics

Cybernetics is a branch of systemic thinking that deals with systems in a highly complex and uncertain environment. Cybernetics originally was defined as

"*the science of communication and control in the animal and the machine*"[82,83].

More recently, Beer[82,83] has defined Cybernetics as

" the science of effective organisation".

Beer[81,82,83,106] developed a systems approach called the Viable System Model (VSM). This is a generic model of an organisation that is intended to achieve viability. A viable system is defined by Beer as a system which is

"able to maintain a separate existence".

The VSM is a model of a learning organisation. It is based on the idea that management is about control of organisations and that the basic difficulty of control is the complexity of organisations in a complex and unstable world. The human brain or more precisely the nervous system is one of nature's perfect examples of how control of complexity can be organised. Beer uses this system as a powerful analogy, or design model, for effective organisation of systems. This is the underlying idea of the VSM. Three principles derived from that analogy are of relevant significance in the VSM: first, the principle of viability, second, the principle of recursion, and third, the principle of autonomy.

The Principle of Viability

Viability stands for an ideal cybernetic behaviour of an organismic adaptation to a changing environment through "intrinsic homeostatic control" [82]. Homeostasis is understood to be equilibrium or balance. Viability or self-adaptation implies the survival or homeostatic adaptation of a system according to its purpose. Beer emphasises that in order to be viable, any system, artificial, organic or social, must have and perform five organisational functions, which constitute the structural prototype of any viable system. A detailed description of this model is given in section 3.2 of chapter 3. System 1, operations, represents the basic productive sub-units of the system. System 2, antioscillatory, co-ordinates the activities of system 1 operations, as well as providing for information aggregation and filtration of upward communication. It also involves communicating, translating and amplification, instructions coming down from system 3 to system 1. System 3, 'inside and now', is concerned with the operations management or internal activities of the system on a day-to-day basis. It is also responsible for routine reports to the next higher level of recursion, from which it receives routine feedback instructions. Systems 4 and 5, finally, represent the levels of strategic and normative planning. System 4, 'outside and future', is the development management, or staff function. It is responsible for monitoring environmental changes and for preparing the future of the system. For example, through market research and marketing, Research and Development (R&D), Operational Research (OR), etc. it develops plans within the framework of the overall policy determined by system 5. Finally, System 5, policy, can be interpreted as representing the 'portfolio' level of normative planning. It deliberates the overall policy and balances the functions of systems 4 and 3. It keeps the ultimate decision authority with respect to the goals of the system.

The distinction between different levels of replication of these five systems of any viable system is the subject of the principle of recursion. This is discussed below.

The Principle of Recursion

The principle of recursion, in Beer's words[106],

"says that all viable systems contain viable systems, and are contained within viable systems. Then if we have a model of any viable system, it must be recursive. That is to say, at whatever level of aggregation we start, then the whole model is rewritten in each element of the original model, and so on indefinitely".

This principle was formulated for the organisation of a viable firm in analogy to that of the brain. Relying on the assumption that this principle describes a universal law, it has been extended to an entire socio-economic system. This is emphasised by Beer[106]:

"If we model the state, then one element is the economic system; if we model the economic system, then one element is an industrial sector; if we model that industrial sector, then one element is a firm. The model itself is invariant. See what happens if we go on with this recursion. An element of the firm is a plant; an element of a plant is a particular shop; an element of the shop is a section; an element of the section is a man. And the man is assuredly a viable system-as a matter of fact, the model started from the cybernetic study of man's effective neurophysiological organisation in the first place".

The principle of recursion is meant to legitimise the application of the structural prototype of the VSM to all socio-economic levels, whether a national government, a branch or sector of industry or a firm. Routine reports and policy instructions are passed from one level of recursion to another level through the system 5 function. The VSM proposes to treat the examination of any organisation, however large, in three levels of recursions. In this way, the 'meta-management' or system 2 to 5 of a viable system is the management unit of system 1 of the next lower level of recursion. The whole structure of the VSM is replicated in each operation of system 1 at the level of recursion next below. This is explained more specifically in section 4.3.

The Principle of Autonomy

According to Beer, the principle of autonomy is a cybernetic answer to the problem of centralisation and decentralisation in organisations, and hence to the problem of participation. It is clear that an effective control of complex systems requires a certain degree of centralisation as well as descentralisation[81,82,83]. Beer stresses that the optimal degree of autonomy, given that the management unit has variety to deploy, is in principle a computable function of the system's purpose in relation to its environment. Variety is a measure of complexity that is defined as the number of possible states of a system. Beer measures the autonomy of a subsystem of system 1 by the possible number of states that it can assume (its horizontal variety) minus the actual number of states excluded by systems 2 to 5 intervention (vertical intervention). To accomplish this, the underlying concept appears to be management by exception, as Beer emphasises:

"if a system regulates itself by subtracting at all times as little horizontal variety as is necessary to maintain the cohesion of the total system, then the condition of autonomy prevails".

"Real Time" Communication

How effective the homeostatic control at each level of recursion is in the VSM depends not only on what feedback information is received, but also on which way and how fast information is received. Traditionally, information in the form of statistics and reports that reach decision makers takes a considerable amount of time. The VSM has effective communication within itself and with its environment. In addition, the VSM suggests "real-time" communication and control so that it relies on information that is currently valid. Each operation of system 1 has to send a daily report on the state of its critical variables to the 'meta-system' and would then receive a daily feedback, which presents an analysis of the implications for its situation. The VSM focuses on the communication and relationships between different parts of an organisation and its outside world. It emphasises that the channels of communication that link its five subsystems, systems 1 to 5, and its environment are capable of coping with the complexity of its environment. These channels obey principles called principles of organisation. These organisational principles are listed in Appendix A. Unless these principles are complied with, the whole organisation will be affected and become ineffective, and this is a threat to its viability.

According to the above, there is not a generally accepted criterion to define an SMS, nor an effective SMS. Systems thinking, on the other hand, suggests that an organisation can be regarded as a system, which may help to understand complex situations. Moreover, cybernetic principles may facilitate the design of a more effective organisation. Systemic ideas can be adopted in designing an effective FSMS, which is described not only as systematic, but, more importantly, systemic in chapter 5. Therefore, a FSMS should be regarded as a system which has interrelated parts, structure, and purpose served by the parts and the structure. Furthermore, an effective FSMS should comply with the principles of a viable system.

2.4 SH&E Management Systems

Because of sophisticated and demanding markets, diverse and rapid technological change, new SH&E regulations and standards, increased importance of fire safety in organisations, a great effort has been made by academics, regulators and industry to research and develop tools and methods to address fire safety, safety and the environment. The following subsections review the most relevant approaches to fire safety, safety and the environment that have been developed and proposed over recent years.

2.4.1 National and International Standards

Numerous organisations have integrated or are considering integration of their SH&E management system into national or international standard-based management systems. The American Petroleum Institute (API)[107] recently introduced two recommended practices. The first is a recommended practice for development of a safety and environmental management programme for outer continental shelf operations and facilities (API RP 75)[62]. The second is a recommended practice document for design and hazard analysis for offshore production facilities; this is a generic 'safety case' for open platforms in mild climates (API RP 14J). The API RP 75 explains the elements that should be considered in a system to manage safety and environmental protection during the performance of oil and gas operations. It is intended to provide guidance on the necessary policies and procedures and the management systems required to ensure that the practice of these procedures is not deficient. The API RP 14J on the other hand details guidelines for safe design according to best practice in industry. It explains how to conduct a hazard analysis of a design and provides details of the recommended safety information required to ensure safe operations.

Additionally, some organisations have adopted the API RP 750[61], which details the purpose of process hazard management as prevention of catastrophic events and this can be accomplished through a management system. It provides guidance to assist in the management of process hazards to help prevent the occurrence of, or minimise the consequence of, catastrophic releases of toxic or explosive materials. The API RP 750 details eleven elements for the management of process hazards. These are process safety information, process hazards analysis, management of change, operating procedures, safe work practices, training, assurance of the quality and mechanical integrity of critical equipment, pre-start up safety review, emergency response and control, investigation of process related incidents, and audit of process hazards management systems. Mark and Peter[108] report an SMS, which was derived from API RP 750, and other standards and regulation requirements. The reported SMS covers a core of fifteen policies, such as leadership and administration, training, planned inspection, test and maintenance, hazard analysis, accident/incident reporting investigation and analysis, emergency planning and response, organisational rules, personal protective equipment, auditing, management of change, communications, contractor safety, purchasing controls, health control, and off-the-job safety.

Some organisations have derived their SMS from environmental standards such as ISO 14001 EMS. ISO 14001 EMS[57] is a formalised method for establishing and meeting environmental objectives. The ISO 14001 Environmental Management System (EMS) consists of five basic principles: first, environmental policy, which is the organisation's commitment to environmental issues and support with the resources necessary for its implementation; second, planning includes the identification of the environmental aspects of the organisation's products, services, and activities along with a strategy outlining the significant aspects in the EMS; this would involve the identification of specific measurable goals and objectives; third, implementation and operation which contain the means and methods for achieving the policy according to the plan; fourth, measurement and evaluation cover the means for monitoring progress to check whether the goals and objectives are being met or not, as well as the procedures to be used to correct possible deficiencies; finally, review and improvement provide the means for periodic review to continually improve the EMS, with the objective of improving the overall environmental performance of the organisation.

Other studies have focused on harmonising international standards such as the ISO 9000 series and ISO 14000 Environmental management Systems (EMS) with Occupational Health and Safety (OHS) management system, such as the OHS management system presented by Dyjack and Levine[109], Levine and Dyjack[110], and Dyjack et al.[111]. It is claimed by the authors that this management system can be easily adapted to the ISO 14001 EMS format. This system is expected to be compatible with current production quality and OHS quality systems and standards. Moreover, ISO 9000 series have been applied world-wide, the incorporation of harmonised OHS and environmental management system components should be acceptable to business units already performing self-auditing and external auditing.

2.4.2 Petrochemical Industry

Several major disasters, such as Flixborough (UK), Bhopal (India), San Juanico (Mexico), Piper Alpha (UK) and many others world-wide have highlighted the need to improve radically the safety performance of organisations. It is now recognised that managerial and organisational factors are key contributors to accidents or disasters[7,12,71]. Several accident investigations have found that 80% correspond to human error and 20% correspond to technical failures. This has been termed the 80-20 rule[7,112]. Moreover, it is claimed in the literature that the root cause of such disasters was the failure of the existing SMS to manage work activities properly.

The importance of human and organisational factors, particularly of the SMS, was highlighted by the Cullen report[24]. Among the factors that need to be addressed are organisational structure, the involvement of the workforce in safety, monitoring and auditing of the operation of the system, and re-assessment of the SMS. Offshore installation regulations require operators or owners to demonstrate that their SMS is adequate to ensure that the statutory provisions will be complied with, and that adequate arrangements for audit are in place. Furthermore, all hazards causing a major accident should be identified and the risks evaluated, and measures taken to reduce these risks so far as is reasonably practicable. This means that any risk must be reduced to a level which is 'as low as reasonably practicable' (ALARP)[87]. The ALARP principle involves determining first whether a given risk is so great or the outcome so unacceptable that it must be refused altogether. Second, it determines whether the risk is, or has been made, so small that no further precaution is necessary. Finally, if a risk falls between these two states, it must be reduced to the lowest level reasonably practicable, bearing in mind benefits flowing from its acceptance and considering the costs of any further reduction.

Many best safety practices of the chemical industry are built on George's and Druker's ideas, as discussed in section 2.2. Planning, organising, implementing and controlling should be the basic functions of an SMS as described for the Centre for Chemical Process Safety (CCPS)[113] guidelines. "Planning" involves policy development and company goals and objectives. "Organising" involves establishing the structure and delineating roles, responsibilities, authority and accountability to accomplish the objectives. "Implementing" provides the mechanisms and executes the policy. Finally, the "controlling" function involves measuring, evaluating and correcting performance. Moreover, many of the larger chemical and petrochemical companies have adopted integrated SH&E management systems[114], which are in some cases further integrated with TQM.

Bentley and Stockley[115] describe a SMS, which integrates a hazard management analysis and quality management. The structure of the SMS consists mainly of three main aspects. First, it requires an understanding of the hazards of the operation or facility. This involves identifying the organisation's processes and activities. Once the processes and activities have been identified, a hazard management analysis (HMA) is conducted. The HMA consists of identification, assessment, control, and recovery. This helps to identify critical activities and processes, which are called 'safety-critical'. Second, for each 'safety critical' activity a combination of documents is prepared. This combination of documents is called the SMS catalogue, which describes how safety is intended to be managed within the organisation. The SMS catalogue closely complies with quality principles. Finally, the organisation's commitment and support are reflected in a separate document called the SMS manual. This manual reflects the organisation's safety objectives and the means by which they can be achieved. These controls include incident reporting, performance indicators, audit and review, continuously monitor, assess and improve the performance of the operations and activities.

Other organisations, such as the European Process Safety Centre (EPSC)[116] have developed SMS guidelines, as well as providing an overview of safety management practices in industry. The key elements of the EPSC safety management may be distinguished as policy, organisation, management practices and procedures, monitoring and auditing, and management review. Similarly, guidelines for the development and application of health and environmental management systems have been developed and proposed by the Exploration and Production (E&P) Forum[117]. These guidelines recommend that policies and objectives are set to take account of hazard information, including environmental effects. The key elements of the SMS recommended by the E&P Forum include leadership and commitment (top-down commitment, etc.), policy and strategic objectives, organisation, resources and documentation, evaluation and risk management, planning, implementation and monitoring and auditing and reviewing.

Ming[94] and Bentley et al.,[118] describe the development and implementation of a 'quality based' SMS, which consists of establishing goals, organising and allocating resources, establishing the performance standards, implementing the plan, and auditing and reviewing the system for compliance and improvement. Ming[94] emphasises that the purpose of the SMS is to provide the necessary assurance that all people affected by the organisation's operations have been protected, as well as safeguarding the environment from damaging incidents, and the assets have been protected. All these measures are applied to the extent that risks are ALARP. Furthermore, Ming contends that the integration of the SMS with quality and the business enables it be an effective safety management, as well as enhancing quality and improving operations management.

The United Kingdom Offshore Operators Association (UKOOA)[44] guidelines for fire and explosion hazard management were introduced in 1995 and prepared to complement the Safety Case regulations. Furthermore, they intend to encourage an integrated approach to the management of fire and explosions offshore. These guidelines include a life cycle approach to fire and explosion hazard management, assessment of fire and explosion hazardous events, inherent safety, selection and specification of systems for fire and explosion detection, control and mitigation and implementation. The UK Health and Safety Executive (HSE)[119] has developed and proposed an approach to safety referred to as Successful Health and Safety Management HS(G)65, which has many similarities with George's[89] ideas of a management system. The HS(G)65 health and safety management's main functions include policy, organising, planning and implementing, measuring and reviewing performance, and auditing to benefit from experience. It also shows how to apply principles of TQM for successful safety management. Finally, the Canadian Pulp and Paper Association has developed a set of guiding principles for managing occupational health and safety (OH&S)[120]. These guidelines are used to audit the SMS of the association member companies. The audit assessed five key components of a SMS for a number of OH&S

activities. System ownership, goals and procedures, measures of performance, review of measures, and corrective action are the key components of a SMS that must be in place.

2.4.3 Transport and Maritime Industry

A number of recent and highly publicised accidents in the transport industry have highlighted the need for operators of public transport to address safety hazards. Despite this need, there are currently few proactive SMSs, which effectively demonstrate improvements in transport safety performance. Bemowsky[121] reports on how the American Federal Aviation Administration (FAA) and the aviation industry are ensuring the safety of the flying public. The author discusses five major initiatives that are intended to address five major causes of air accidents. The first of these is weather-related accidents, the FAA has taken steps to improve weather services. This includes the development of terminal Doppler weather radar, low level wind shear alert system, next generation radar, integrated terminal weather, and weather and radar processor. The second is aircraft related accidents; many of the Federal Aviation Regulations (FARs) and statutes prescribe the safety and quality standards that organisations and personnel in the aviation industry must follow regarding the design, manufacture, and operation of aircraft. The third is air traffic related accidents; the FAA has taken several measures to reduce operational errors, such as eliminating pilot-controller communication errors, and eliminating surface errors. The aim of these measures is to provide a cost-effective communications infrastructure to enhance both the safety and effectiveness of air traffic management. The fourth is human error related accidents; it is recognised that human factors cannot stand alone, but they apply in everything the organisation does. Several actions address the vulnerabilities of maintenance, management, regulators, flight crews, etc. The fifth is malicious acts-related accidents; measures are taken to ensure aviation security against the threat of terrorism. These measures include not only explosive detection devices, but also non-technological improvements, representing a shift from an adversarial relationship to partnership between government and industry.

A study conducted by Degani and Wiener[122] identified and integrated an aviation organisation's philosophy, policies, and the standard operating procedures (SOP) for cockpit operations. The authors argue that in high risk endeavours such as aircraft operations, space flight, nuclear power generation, manufacturing process control, and military operations, it is essential that procedures be flawless, as the price of operational error can be unacceptable. The organisation's philosophy involves determining how the organisation conducts the business of the airline, including flight operations. The organisation's philosophy is largely influenced by the organisation's culture. Policies are broad specifications of the manner in which management expects things to be done, such as training, flight operations, maintenance, exercise of authority, personal conduct, etc. To support the organisation's policies, a set of operating procedures is developed and provided for the flight crews. A procedure intends to specify unambiguously what the task is, when the task is conducted (time and sequence), how the task is done (actions), by whom it is conducted, and what type of feedback is provided to other crew members.

Edkins[123] presents a safety programme called Identifying Needed Defences In the Civil Aviation Transport Environment (INDICATE) for the Australian airline industry. The INDICATE uses five criteria which are used to evaluate an airline's safety performance. These criteria include airline safety culture, staff risk perception of aviation safety hazards, willingness of staff to report safety hazards, action taken on identified safety hazards, and staff comments about safety management within the airline. The author contends that the programme can have a positive influence on airline safety performance, specifically on improving staff confidence in how safety is managed. It also can increase staff willingness to report safety hazards and incidents, improve organisational safety culture and reduce staff perceptions of the severity and likelihood of safety hazards occurring within the airline.

Safety and fire safety have gained importance in the maritime industry also. The International Maritime Organisation (IMO) has adopted a number of initiatives that intend to improve fire protection, safety and pollution prevention, particularly on vessels and ships[124,125]. Rodricks[124] describes a system for managing fire safety on passenger vessels. It consists of a number of controllers for monitoring the various safety subsystems. The controllers are linked to a local area network (LAN) and managed by a computer (Saturn II). Control terminals can be dispersed round the vessel to enable operators to monitor events simultaneously. The SMS involves four main aspects, such as communication, graphic displays, command and control, and fire fighting procedures. More recently the guidelines for the International Safety Management (ISM)[125] code were also adopted by the IMO. The code and its guidelines involve safeguarding maritime safety and protecting the marine environment. They intend to provide safe practices in ship operation and a safe working environment, and to establish safeguards against all identified risks. They also aim to improve continuously the safety management skills of personnel ashore and aboard, including preparing for emergencies both to safety and environmental protection.

Research has identified characteristics of high reliability organisations (HRO), which have had few accidents while involved in operations where failure would be catastrophic[126]. These characteristics have important impacts on the safety of marine systems, such as offshore platforms, marine terminals, ships and vessels. Hee[126] et al., report a safety management assessment system (SMAS), which was developed to assess human and organisational factors in marine systems. The SMAS is a screening method that selects and trains operators of the system to conduct a self-assessment process. The assessment process takes five days and has the assessors making comparisons and evaluating human and organisational factors by selecting ranges and providing comments to capture the uncertainty. A computer program was developed to assist in the assessment process. A study conducted by Edkins et al.[127], applied the REVIEW method developed by Reason[7] within an Australian public rail authority. The REVIEW method helps to identify latent failures that pose a threat to system safety. It was found to be useful, especially from a participative safety management perspective, and for targeting safety areas that need current attention. Factor analysis revealed that policy and decision making, workplace culture and operating conditions were the most critical. It is argued that these findings imply that the most effective way to minimise workplace accidents is to devise actions for the most global features of the organisation.

2.4.4 Power Generation and Other Industries

Kidd[128] asserts that there are several factors which might make gas turbine plants more vulnerable to fire than 'conventional' power stations. The author also discusses some aspects of an emerging Code of Practice, which focuses the potential for fire in the production of electricity using gas turbines, cogeneration, and combined heat and power. Although the size and layout of gas turbines can vary greatly between manufacturers, the components which comprise the gas turbine remain the same. It is stressed that some components of the gas turbine have a higher fire risk than others, hence the need for fire risk management in these components. These components include air inlet systems, exhaust systems, the turbine compressor, blade-cleaning equipment, combustion chambers and ignition system, the power turbine, turbine gearing, starting equipment, turbine integral fuel system, the lubricating oil system, cooling systems and transformers. Xiao et al.[129] , on the other hand, discuss how to ensure the quality of a fire safety system in buildings. A fire safety assurance system is described by the authors as a combination of a "hardware" subsystem and a "software" subsystem. A "hardware" subsystem consists of all the fire protection equipment and facilities. A "software" subsystem, on the other hand, involves managerial measures concerned with fire safety, such as training of staff, operation and maintenance of equipment, and emergency plans. The hardware subsystem is referred to as the fire safety system, which has several components, such as a passive fire protection system, fire detection and alarm system, fire suppression system, evacuation system, smoke-control system, and emergency lighting system.

Organisations in other kinds of industries, such as the cement industry, are also adopting environmental management systems. Adams and Niehoff[130] found that the cement industry has developed health and safety management, operational management and emergency management. They also discuss both the integration of these management systems so that they are as streamlined as possible and hence acceptable to employees, and reduction in the amount of documentation and auditing. The authors contend that the integrated management systems can improve the security of the company not only through technical measures but also through a closed and controlled organisation.

Other writers have taken a quality "systems-wide" approach to gain an understanding of the root causes of accidents. Ansari and Modarress[131] described a systems-wide approach to safety adopted by the Boeing Company. They identified five areas that contribute to a safe work environment. They further identified a full range of paths to be taken and tasks to be accomplished in order to achieve the desired safety goals. The five key areas that would make the transition to "world-class safety performance" are executive leadership, safety improvement processes, training, alternative work programmes and return-to-work, and communication. Executive leadership involves top management commitment, promotes a strong safety culture, establishing a top-level steering committee, gives the highest organisational priority to the safety improvement process, and adopts a new framework to evaluate safety performance accountability. The safety improvement process involves developing clear corporate policies and objectives which ensure that process standards, guidelines and procedures that improve shopfloor safety processes are implemented. Training is seen as a critical factor leading the company towards the "ultimate in safety performance". Alternative work programme/return-to-work involves reducing lost time injuries (LTI), return to work as soon as possible and in a safer and more productive environment. Finally, communication: it is crucial to communicate effectively with everyone in the organisation. A study conducted by Wilkinson and Dale[132] reports the integration of quality, environmental and occupational health and safety management systems in manufacturing organisations. This study found that manufacturing companies are less interested in occupational health and safety management systems. Whilst ISO 14001 EMS is preferred to Environmental Management and Auditing Schemes (EMAS), it is claimed by the authors that those organisations which have embraced the principles of TQM are more likely to "pursue integration" than those that have not.

Wilson and Koehn[133] argue that the process of controlling safety policies, procedures, and practices is currently being implemented by many construction companies. This limits construction companies' liabilities and costs in order to remain competitive in the construction market place. Construction companies face the most difficult obstacles during the implementation phase of safety management because very often the workers present the greatest opposition. However, they are the same individuals who benefit the most by improved safety conditions on the site. The authors contend that safety management is a dynamic process operating in a constant state of change. Therefore, the process must be constantly monitored and adjusted to achieve the desired goals.

2.5 Methods and Tools

Particular interest has been given, by both academe and practitioners, to developing methods and tools that may help to measuring the safety performance of organisations. Various approaches to measuring an organisation's safety performance have been suggested in recent studies, often to define goals for what must be done and to develop criteria that are measurable. In general, it is claimed that this goal-setting approach is more proactive, but it is still addressing technical aspects. This section discusses how organisations address risks and how they measure their safety performance.

2.5.1 Measuring Safety Performance

Organisations use a wide variety of indicators both to check the implementation and identify strengths and weaknesses of their SMSs. Results of such assessment processes are usually checked and compared with the organisation's safety goals. When these safety goals are not complied with, it is common to conduct safety audits. An audit process of a SMS traditionally verifies the existence and implementation of safety objectives, standards, and procedures. The outcome of an audit is used to 'validate' the effectiveness of the SMS. It is common in practice that the assessment and measurement of the performance of a SMS are part of an audit system.

Roughton[92] stresses the need to measure behavioural indicators, look at accident frequency less often and look at other upstream behaviour indicators on a day-to-day basis. He suggests identifying critical behaviours using the analysis of previous accidents and employees' perceptions, and conformance with requirements as well as providing feedback on safe behaviour performance. Moreover, the action taken by management to affect the safety and health system positively, and a sample of unsafe practices, behaviours and conditions are two key indicators that should be measured.

In the oil and gas industry significant efforts have been made to develop measures of safety performance. Hudson et al.[19,134,135], and Reason[7] propose a framework, called Tripod Delta, that addresses human errors, which can be seen at both individual and organisation levels. It is claimed by the authors that this framework provides an indication of 'latent errors', which are characterised into eleven factors called general failure types (GFT). This approach assesses the "safety health" of an activity or operation using the GFT as the key indications. In order to do so, first checklists are made up of a number of indicators as questions are derived from each GFT. An indicator is an indication that something is not functioning properly. Questions for each GFT are drawn from a larger collection in a database. Many unacceptable answers to the indicators for a specific GFT strongly indicate underlying problems associated with that GFT. Second, a profile score is computed for each GFT by simply adding the number of indicators that were answered in an unacceptable way. The worst score would be twenty, while the best would be zero. Third, remedial actions are defined in the last step of the approach. The authors stress that it is possible to select actions for their feasibility and effectiveness rather than being driven by the immediate consequences of an incident or accident. Finucane[135] and the UKOOA[44] describe key ideas embodied in the concept of safety performance standards. The UKOOA contends that with the goal-setting approach it is possible to define overall goals for design and operation, together with a method for assessing the extent to which these are accomplished. Moreover, it is stressed that for any goal it is possible to identify one or more measures whose performance would be an indicator of how successfully the goal is achieved. These measures of safety performance are known as performance standards. Finucane suggests a hierarchy of high, medium and low performance standards levels, whilst the UKOOA discusses high and low levels. High level performance standards indicate the safety performance of the organisation's installation as a whole. In general, they indicate individual risk and fatal accident rate that have to be satisfied by the organisation. Low levels of performance standards, on the other hand, are applied to subsystems, and components of subsystems. These performance standards are defined by considering functional capability, reliability/availability, and survivability. However, these measures of safety performance still address safety and fire safety in isolation concerning the business and human factors. It is argued elsewhere[136] that what is needed is an integrated measure of performance that supports rather than contradicts business objectives.

Hurst[137] reports the findings of a study conducted by the Field Operations Division (FOD) of the HSE. The FOD developed a method called Structured Audit Technique for the Assessment of Safety Management Systems (STATAS). This audit technique is now included within a set of tools and techniques known as 'The FOD Guide to the Inspection of Health and Safety Management'. The tools and techniques contained in the FOD Guide provide for assessment of management arrangement, assessment of risk control systems, and assessment of safety culture. Management arrangements are the managerial methods by which an organisation sets out to determine and provide adequate controls of hazards. Risk control systems set out the way systems and workplace precautions are implemented and maintained. They form a logical structure resulting in effective control of risks. Other oil and gas organisations, such as the Exploration & Production (E&P) forum, have developed a set of guidelines on Quantitative Performance Measure of SH&E Management System Effectiveness[138]. These guidelines have been developed to be applicable to different companies, to recognise the role of contractors and to facilitate operation within a statutory framework. The documents include means of developing metrics for each of the seven elements of the SMS developed by the E&P Forum[117], as discussed above. For each element there are sample questionnaires to be used to survey or assess performance.

Similarly, Hauptmanns[139] presents a procedure for assessing the quality of safety management. This method is based on a set of questions concerning areas of relevance which have to be answered with value statements. These value statements are represented by fuzzy numbers, since they are vague statements. They are combined mathematically to judge the quality of management of the whole as well as that of the different areas considered so that weaknesses can be identified. It is claimed by the author that this technique has the potential for replacing some of the safety analysis and auditing procedures currently in use. Papazoglou and Aneziris[140] propose to use the information of safety management audit and the basic events of a QRA to assess the effects of organisational and management factors in chemical installations. An audit process establishes the relative position of the organisational and management aspects of a particular chemical installation concerning the organisation's safety goals. A QRA including detailed system analysis offers a plant-specific decomposition of the plant-damage-state frequencies into events like hardware failures, maintenance-related failures, operation-related failures and so on. The basic events incorporated in the QRA can be categorised into classes similar to those explored by the management audit and are quantitatively linked to the audit results. Knowledge of these quantitative links would help to identify deficiencies or strengths that might exist in the safety management system on the quantitative risk indices.

Gawande and Wheeler[141] present measures of effectiveness (MOEs) for a maritime safety programme. The MOEs are applied into an overall "programme level" and into a "component activity level". Poisson models and data on maritime accidents from a real-time marine safety management system database are used to construct the MOEs. A distinctive characteristic of this approach is the Bayesian estimation of missing data. It is emphasised by the authors that the MOEs have four important uses. First, they are indicators of efficiency. Second, they can be used as inputs into allocative decisions within the organisation. Third, performance evaluation can be conducted for specific marine safety activity through the component activity level. Fourth, and possibly the most important, MOEs provide the basis for better regulation by the government. Mitchison and Papadakis[100] stress the need to measure safety performance through the use of performance indicators, which consist of output measurements and indirect indicators. This will enable practitioners to evaluate the effectiveness of an SMS on site. They contend that safety performance is a measure of the completeness and adequacy of an SMS operating on site. A SMS can be fully operational only when a number of control loops integrate effectively all relevant elements at all levels of operation. Such control loops typically include policy, standards and norms, implementation procedures and training, operators and equipment reliability, and monitoring and control revision. Moreover, they emphasise that approaches based on proactive indicators examine weaknesses and malfunctions of the SMS, preventive actions which control the risks, the use of output measures to evaluate results and ends, and accident causation factors.

Safety management auditing is a common means of assessing the performance of a SMS[97]. Reactive indicators such as fatal accident rate (FAR), lost time injury (LTI) rate and other output indicators have been used extensively in assessing process safety performance[64]. Other indicators such as loss of containment rates (LOC) and positive indicators such as the ratio of "positive observations" to the "total number of observations" are considered in some approaches[142,143].

2.5.2 Hazard Management

Bentley and Stockley[115] integrate a hazard management analysis (HMA) into a SMS. This HMA has four basic steps that can be applied in any situation. These steps are described as identification, assessment, control, and recovery. The identification steps involve identifying what can go wrong and what and who will be affected. Assessing risks and consequences, and specifying control and recovery methods activities are conducted in the assessment step. Control involves applying principles, such as eliminate and minimise, control through design, controls through procedures and practices, what is permissible given the recognised hazards. Finally, the 'recovery step' consists of devising actions to mitigate, contain, deal with contingencies, and recover to achieve a 'normal situation'. The authors emphasise that the HMA can be applied to any activity from the design of a major offshore platform to changing a valve.

More recently, 'inherently safer design' principles have been integrated into the typical HMA. The main elements of this hazard management are quoted as hazard identification, hazard assessment, and hazard management by prevention, control, and mitigation. The measures used to prevent, control, and mitigate the risks can be inherent in the fundamental design. These measures can be specific engineered systems, which can be active or passive, or be provided by operator and management actions or by some combination of these. The concept of 'inherent safety' has been used to describe those aspects of the fundamental design, which can be used to prevent, control or mitigate the risks[144,145,146,147]. These principles have the advantage that they address the underlying source of risks, and make use of existing equipment and systems thus avoiding the need for expensive 'add-on' safety measures, which can fail or be neglected. Srinivasan and Venkatasubramanian[148] propose an integrated approach to Process Hazards Analysis (PHA) called PHAzer. The researchers contend that this approach takes a more comprehensive approach to the entire PHA process. PHAzer uses qualitative 'digraph' based models of units and operations to identify hazards, dynamic mathematical models to perform detailed safety evaluation, and digraph and fault tree models to synthesise and analyse fault trees.

2.6 Lessons Learnt from the Review process

The approaches reviewed in this chapter represent significant changes in addressing safety and fire safety in particular. Researchers and practitioners seem to put emphasis on some management functions, guidelines, and industry standards, including quality principles, to establish a SMS. There is, however, very little attention given to the coherence of the different management functions that constitute a SMS. Existing SMSs seem to lack adequate organisational structure that may help organisations to structure decision making, communication, and safety culture. Culture and safety culture have been a subject of a large amount of research and publication in the literature. Detailed aspects of safety and fire safety culture are not dealt with here. However, culture has been defined as "a system of shared values (what is important) and beliefs (how things work) that interact with a company's people, organisational structures, and control systems to produce behavioural norms (the way we do things around here)"[149].

While the individual SMS elements can normally be identified and evaluated, the inter-linking of these elements into an organisational structure, including procedures, rules and other management tools, are poorly understood in safety and fire safety literature. These aspects can have a role in making a SMS more rather than less effective. Moreover, very little attention has been given by both academe and practitioners to understanding the appropriate degree of interdependence amongst the parts that constitute an organisation in order to design an effective SMS. In addition, the impact of the organisation and structure on the effectiveness of the SMS, as well as on the subsystems of the SMS, is not well understood. Fire safety is still being addressed in isolation. It is further contended in this research project that accidents or disasters are the result of a systemic failure. Therefore, there is a need for a systemic approach to safety and to fire safety in particular that may help organisations to address safety as a coherent whole.

2.7 Conclusion

This chapter has reviewed relevant existing literature on safety and fire safety in the context of SH&E. It started by discussing concepts of safety management, as well as stating some research questions. The chapter proceeded by discussing some key principles of systemic thinking. Existing literature on SH&E management systems within different industries was reviewed. Approaches to measuring safety performance and hazard management were also reviewed. Finally, the last section of the chapter draws some key lessons gained from the review process. The thesis continues by presenting two systemic approaches in chapter three.

Chapter Three

Approaches to Systems

3.1 Introduction

Chapter two discussed existing definitions of an SMS and developed some research questions, as well as considering some key aspects of systemic thinking. It provided a general appreciation of the existing literature on SH&E. This was in the context of the research problem and questions. This chapter extends chapter two by describing two systemic approaches that were adopted to address the research problem and questions. Section 3.2 summarises the Viable System Model (VSM), which was developed to design effective organisations and assess existing ones. The Failure Paradigm Method (FPM) is presented in section 3.3. Finally, section 3.4 gives a summary of this chapter.

3.2 The Viable System Model (VSM)

The VSM was developed and proposed by Stafford Beer[81,82,83]. Beer is one of the founders of cybernetics, which may be regarded, in essence, as the science of communication and control or, more generally, the science of effective organisation. A Viable System is defined by Beer as that which is able to maintain a separate existence. Moreover, Beer contends that in any viable system there are five necessary and sufficient subsystems interactively involved in any organism or organisation that is capable of maintaining its identity independently of other such organisms within a shared environment.

As can be seen in Figure 3.1, if a system is to be viable it needs to achieve five functions associated with systems 1 to 5. System 1, *operational elements*, consists of various

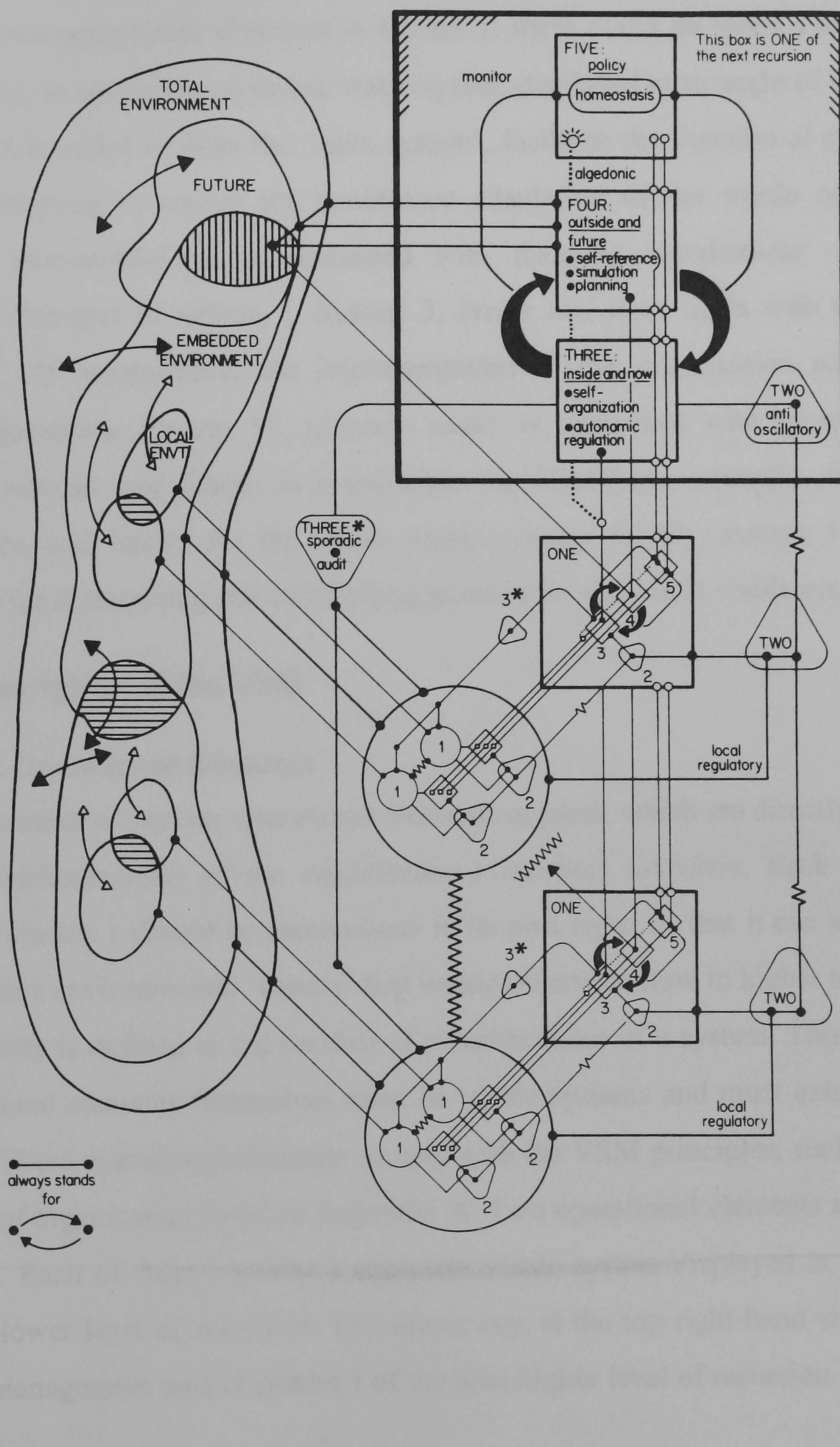


Figure 3.1 The Viable System Model (From Beer[83])

operations of the organisation that are essential to the organisation; that is, the operational elements deal directly with the 'business activities' of the organisation. The operational elements themselves are viable systems. Beer emphasises that in a recursive organisational structure, any viable system contains and is contained in a viable system. So, system 1 is always a viable system in its own right. A complete viable system is illustrated in Figure 3.1, where the interacting subsystems are labelled 1 to 5. It can also distinguish two operational elements in system 1; there could be more. Each contains five functions, or contains a complete viable system displayed at an angle of 45 degrees. Systems 2 to 5, called by Beer the 'meta-system', facilitate the function of system 1, as well as attempting to ensure the continuous adaptation of the whole organisation. System 2, *anti-oscillatory*, is concerned with damping 'oscillations' among the operational elements of system 1. System 3, *inside and now*, deals with the internal stability of the organisation, the implementation of the organisation policies, and resource allocations. System 3*, *sporadic audit*, is concerned with sporadic audits. System 4, *outside and future*, is responsible for identifying strengths, weaknesses, opportunities, and threats for the whole viable system. Finally, system 5, *policy*, is responsible for determining and establishing policies for the whole viable system.

3.2.1 Description of the VSM

System 1: Operational Elements

System 1 consists of various operational elements or parts, which are directly concerned with the *implementation of the organisation's business activities*. Each operational element of system 1 should be autonomous in its own right, so that it can absorb some of the massive environmental 'variety' that would otherwise flow in higher management levels. Variety is defined as the number of possible states of a system. This means that the operational elements themselves must be viable systems and must exhibit the five functions. These operational elements comply with the VSM principles, such as the four principles of organisation listed in Appendix A. Two operational elements are shown in Figure 3.1. Each of them contains a complete viable system displayed at a 45 degree angle at a lower level of recursion. The square box at the top right-hand side of Figure 3.1 is the management unit of system 1 of the next higher level of recursion.

System 2: Anti-Oscillatory

System 2 deals with *damping oscillations* amongst the interaction of the operational elements of system 1. This is a necessary function to ensure that the various operational elements of system 1 operate in harmony.

System 3: Inside and Now

System 3 has a control function responsible for maintaining the *internal stability* of system 1. It must ensure that system 1 implements the whole organisation's policy effectively. To ensure this, it allocates resources to the operational elements of system 1, and carries out 'sporadic audits' using an auditing channel as shown in Figure 3.1. In general, system 3 involves the functional activities that regulate corporate activities in the 'inside and now' and the short-term future.

System 4: Outside and Future

System 4 involves identifying all relevant information about the system's total environments; that is, 'outside and future'. It identifies all relevant opportunities and threats to the system. It is also concerned with obtaining all relevant information about the internal strengths and weaknesses of the system. Moreover, system 4 rapidly transmits urgent information, 'algedonic signal', from systems 1, 2, and 3 to system 5. System 4 is that part of the system or organisation where internal and external information can be brought together.

System 5: Policy

System 5 is responsible for deliberating *policy* for the whole organisation. It balances the sometimes antagonistic internal and external demands placed on the organisation, as represented by the requirements of system 3 and system 4 respectively. This is illustrated in the homeostatic loop between systems 3 and 4, as illustrated in Figure 3.1. It also represents the whole system to any wider system of which it is part.

The VSM and its Environment

The VSM specifies five functional imperatives which are necessary for a system to remain viable; also it has to achieve requisite variety in dealing with the complex environment with which it is faced. The system, in other words, must be able to respond appropriately to the various threats and opportunities identified in its total environment. The structure of the VSM represents a system as interacting in a defined way with its environment through the operations of system 1 and through system 4, as shown in Figure 3.1. In the same way, the embedded viable systems are shown as interacting in exactly the same way with local environments that are peculiar to each of them, though they are subsets of the total environment. System 4 deals with the total environment of the VSM into which the whole system is embedded. It deals also with the 'problematic environment', which is also embedded into the total environment of the VSM. The 'problematic environment' is concerned with threats and opportunities for future adaptation of the whole system. On the other hand, system 1 operations deal with local environments into which they are embedded. These local environments are subsets of the total environment, as illustrated in Figure 3.1.

Communication and Control

Attention is given in the VSM to the information channels linking systems 1 to 5, and the organisation and its environment. Thus, whenever a line appears that is delimited at each end by a dot this represents a homeostatic loop. Each of these lines stands for a pair of arrows looking like the pair that connects systems 3 and 4, or the pair connecting the two operational circles of system 1. The squiggly lines connecting the operations of system 1 indicate an inter-dependency, which may be strong or weak according to the purpose of the viable system concerned. These channels of communication, and the necessary transducers translating information when it crosses system boundaries, must be designed according to the requirements of Ashby's law of requisite variety[150] which states that 'only variety can absorb variety'. It follows therefore that the four principles of organisation must apply to each of these channels of communication. The four organisational principles are listed in Appendix A. The two directional arrows represented in the VSM total environment indicate also a homeostatic loop, and the same organisation principles should be applied to them. A special channel, called an 'algedonic' filter, represented as a dotted line in Figure 3.1, is employed to communicate particularly important signals, which may require the intervention of system 5.

There is a particular concern in the VSM about the nature of the information which flows in the communication channels. This will often, given the importance of negative feedback for control, be information about how the different subsystems of the organisation and the organisation as a whole are doing in relation to their respective goals. Beer suggests adopting his measures of achievement, which consist of three levels of achievement namely, actuality, capability, and potentiality. As can be seen in Figure 3.2, these levels can be combined to give three indices, productivity, latency, and performance, expressed in ordinary numbers. Moreover, the levels of achievement can be used to develop programmatic, strategic, and normative plans. These levels, plans, and indices can be used as comprehensive measures of performance. Moreover, this system can include all types of resources throughout an organisation. The levels of achievement can be defined as below:

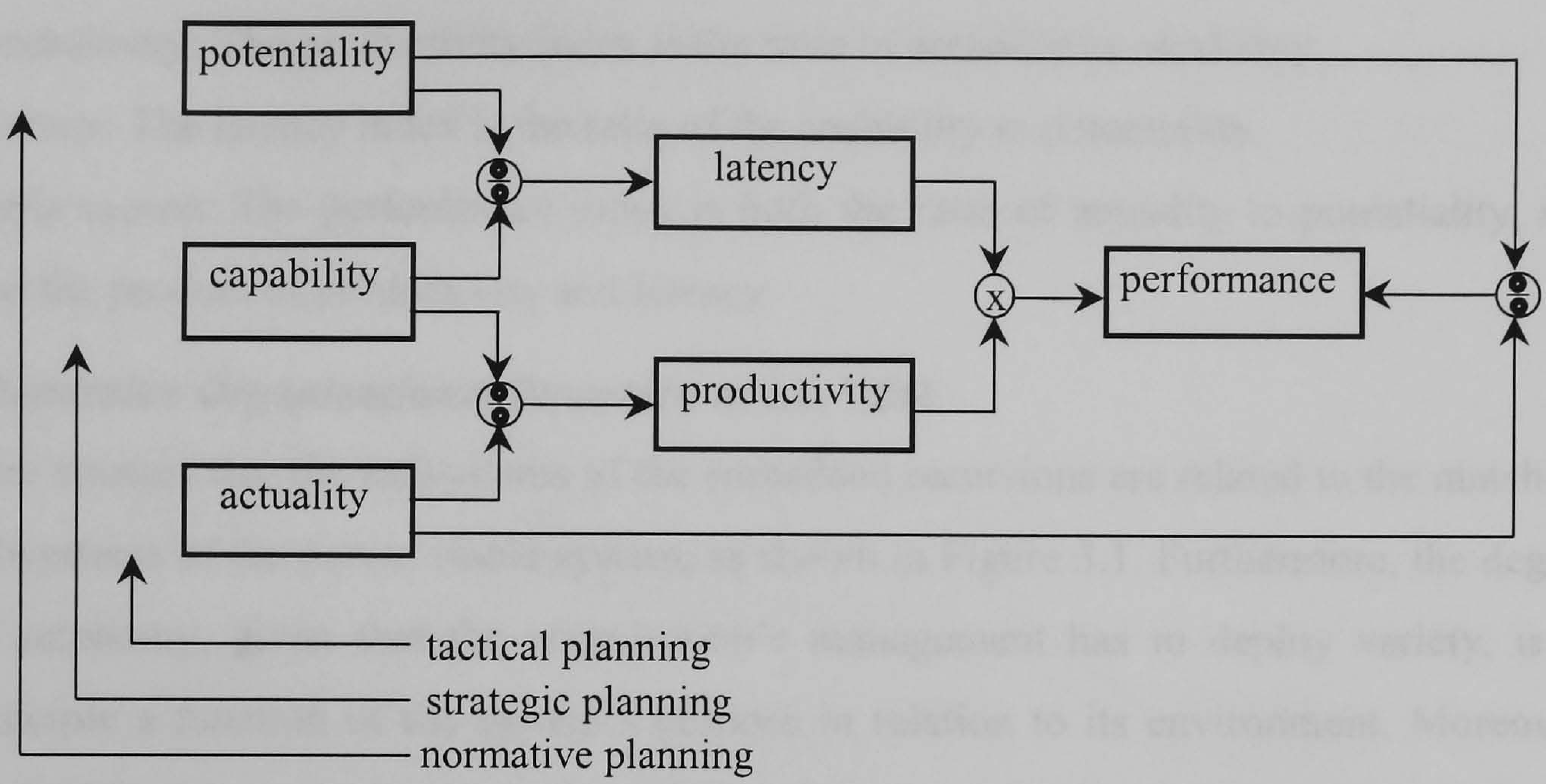


Figure 3.2 Measures Of Achievement (from Beer[106])

Actuality: This is simply what an organisation ***is*** managing to do now, with existing resources, and under existing constraints.

Capability: This is what an organisation *could* be doing (right now) with existing resources, and under existing constraints, if the organisation really worked at it.

Potentiality: This is what an organisation ***ought to*** be doing by developing its resources and removing constraints, although still operating within the bounds of what is already known to be feasible.

An organisation may project its future plans according to these levels of achievement. Three sets of plans can be derived from the three levels of achievement, as follows:

Programming (tactical): Planning from the 'actuality level' of achievement is called programming or tactical planning. It accepts the shortcomings of the situation, and does not admit that anything can be done about them.

Planning by Objectives (strategic): Planning from the 'capability level' of achievement is called planning by objectives or strategic planning. This planning sets new objectives and tries to achieve them. This is the strategic planning level.

Normative Planning: Planning from the 'potentiality level' of achievement is called normative planning. It sets potentiality as its target. It may incur major risks and penalties, but also may offer major benefits.

The three levels of achievement are combined to derive three different indices, as shown in Figure 3.2. They are:

Productivity: The productivity index is the ratio of actuality to capability.

Latency: The latency index is the ratio of the capability to potentiality.

Performance: The performance index is both the ratio of actuality to potentiality, and also the product of productivity and latency.

Recursive Organisational Structure of the VSM

Beer stresses that the subsystems of the embedded recursions are related to the matching subsystems of the parent viable system, as shown in Figure 3.1. Furthermore, the degree of autonomy, given that the organisation's management has to deploy variety, is in principle a function of the system's purpose in relation to its environment. Moreover, the VSM proposes to treat the examination of any organisation, however large, in levels of recursions. This is facilitated by the Recursive Systems Theorem. According to this theorem, in a recursive organisational structure, any viable system contains, and is contained in a viable system. This means that the organisational structure of the VSM as a whole is replicated in each operational element of system 1. As can be seen in Figure 3.1, the VSM is shown with its pair of recursions, where the square box at the top right-hand side is the management unit of system 1 of the next higher recursion. It also shows the level of recursion next below at an angle of 45 degrees.

3.3 The Failure Paradigm Method

The Failure Paradigm Method (FPM) was developed by Fortune and Peters[85]. The FPM is intended to facilitate a systemic interpretation of a system's failure and its context that could lead to some action. This systems approach to understanding failure consists of two key stages. First, conceptualisation, and modelling of the failure situation as a system should be completed. The conceptualisation is accomplished by considering a situation and using diagrammatic techniques to represent it. This could improve the understanding and may enable conceptualisation of the system or systems that can be said to be the core of the failure. Once the conceptualisation has been completed, the system is then modelled; that is, the system is described in a format of an idealised system. Second, comparison of the conceptualised system or systems with a model of a purposeful system without failure should be made. The conceptualised system or systems are further compared with other models, such as control and communication, safety culture, human factors, and structural organisation. A detailed representation of the FPM is shown in Figure 3.3. In general, it should be emphasised that the FPM has been applied to analyse past failures, such as for example the Boeing 737 fire at Manchester Airport (1985), and the Bhopal disaster (1984). However, this research project has used the FPM to analyse a system that has not yet failed. This section will therefore concentrate on the second stage of the FPM, as described below.

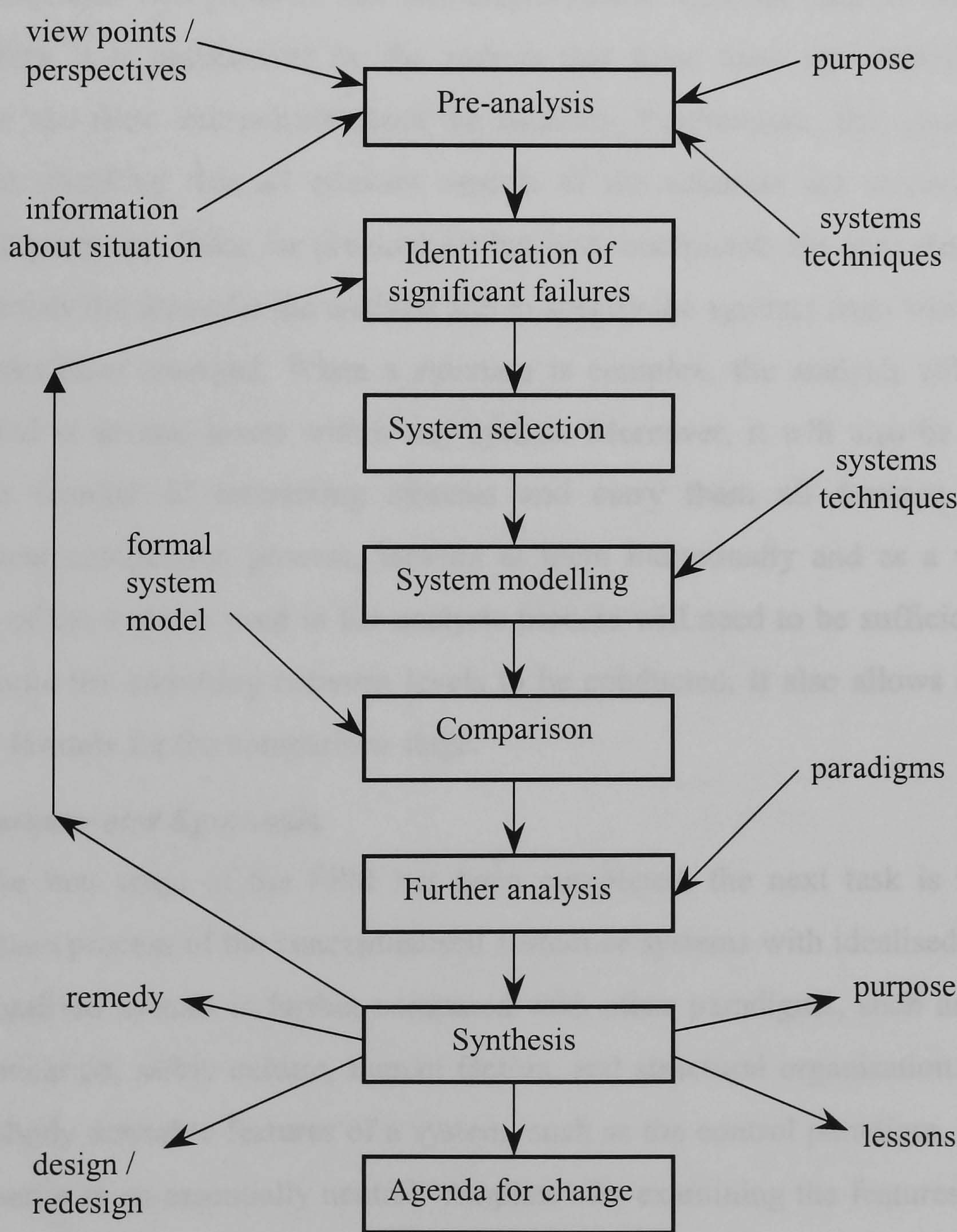


Figure 3.3. The FPM (from Fortune and Peters[85])

3.3.1 Description of the FPM

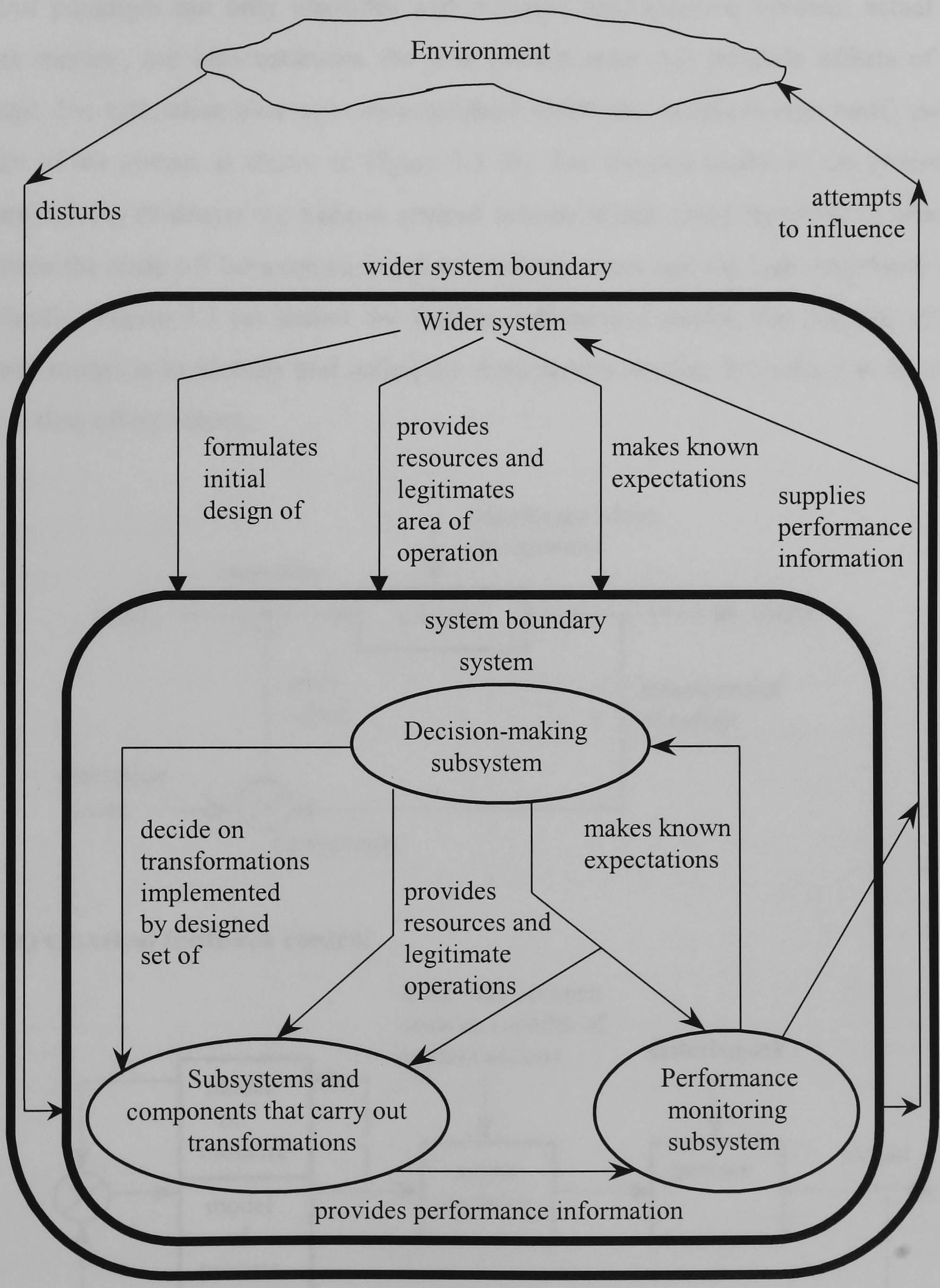
From Situation to System

The first task in the FPM is to conduct a pre-analysis, as illustrated in Figure 3.3. The pre-analysis involves gathering and organisation of information about the failure situation. This stage begins by deciding which aspects of the situation can be regarded as the failure or failures. The purpose of the analysis and the different viewpoints and perspectives that must be considered, information about the situation and its history should be gathered and brought together. Fortune and Peters suggest several techniques to accomplish this stage. They include spray diagrams, relationship diagrams, multiple-cause diagrams, rich pictures, and non-diagrammatic methods such as lists, databases, and charts. It is emphasised by the authors that these tools and techniques help to organise and store information about the situation. Furthermore, they provide working tools for checking that all relevant aspects of the situation are considered and for generating options. Once the pre-analysis has been completed, the next step of the FPM is to identify the focus for the analysis and to specify the systems from which the failure or failures have emerged. When a situation is complex, the analysis will have to be conducted at several levels within any system. Moreover, it will also be necessary to select a number of interacting systems and carry them all forward through the subsequent comparison process, looking at them individually and as a whole. Next, models of the systems used in the analysis process will need to be sufficiently detailed to facilitate the switching between levels to be conducted. It also allows structure and process formats for the comparison stage.

Comparison and Synthesis

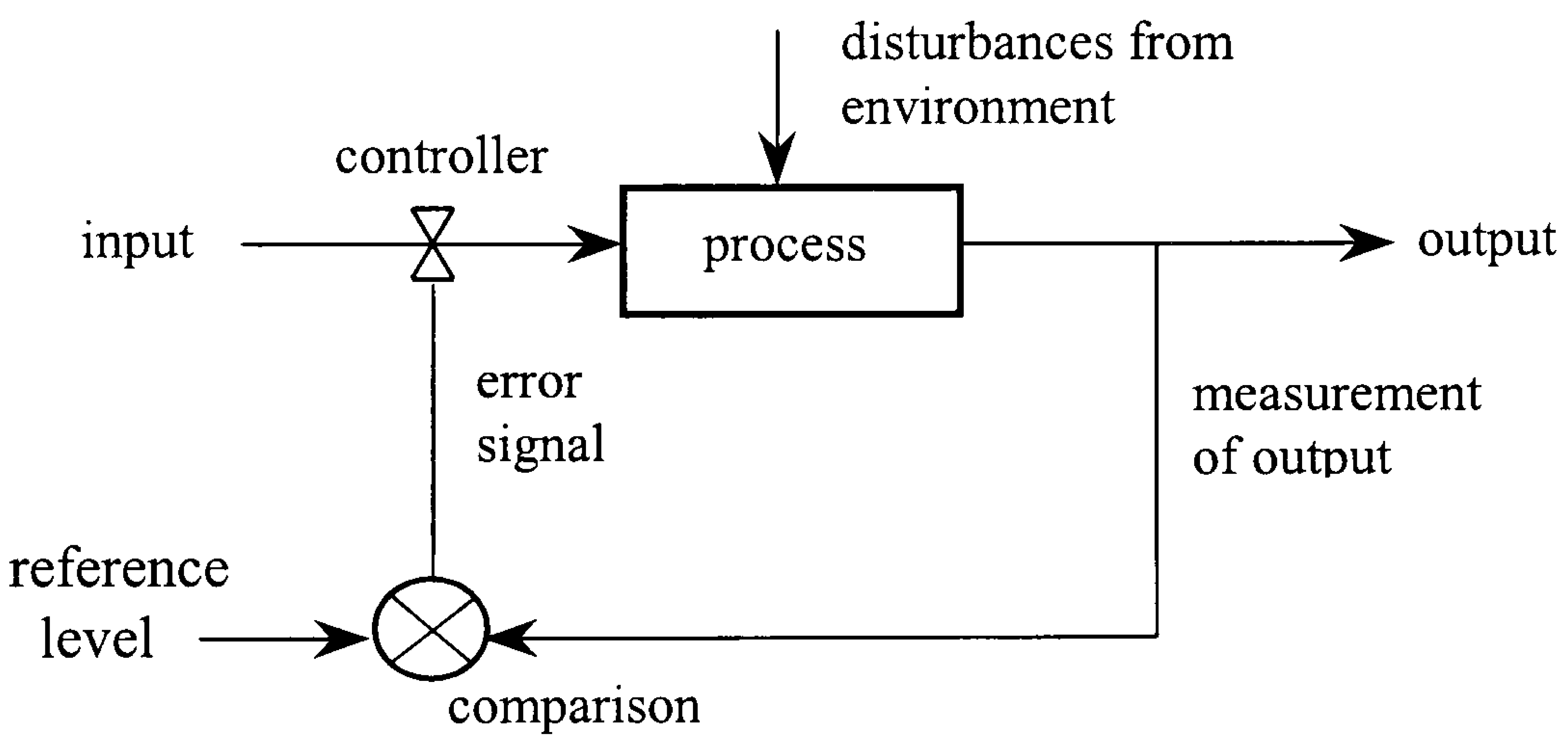
Once the first stage of the FPM has been completed, the next task is to conduct a comparison process of the conceptualised system or systems with idealised models. The conceptualised system is further compared with other paradigms, such as control and communication, safety culture, human factors, and structural organisation. A paradigm may embody desirable features of a system, such as the control paradigm. Alternatively it may serve as an essentially neutral 'template' for examining the features of a system. Paradigms may be used to compare with their counter-parts in a failed system.

The main paradigm of the FPM is 'The Formal System Model' (FSM), as illustrated in Figure 3.4. This model may be used to map onto a 'significant failure', identified as part of a failed system. The main components of the FSM include the environment which the system interacts with, a 'decision-making subsystem', a 'performance monitoring subsystem' and a set of elements or subsystems which perform the activities of the system. The FSM is hierarchical. The wider system may become the system in focus for a different level of study.

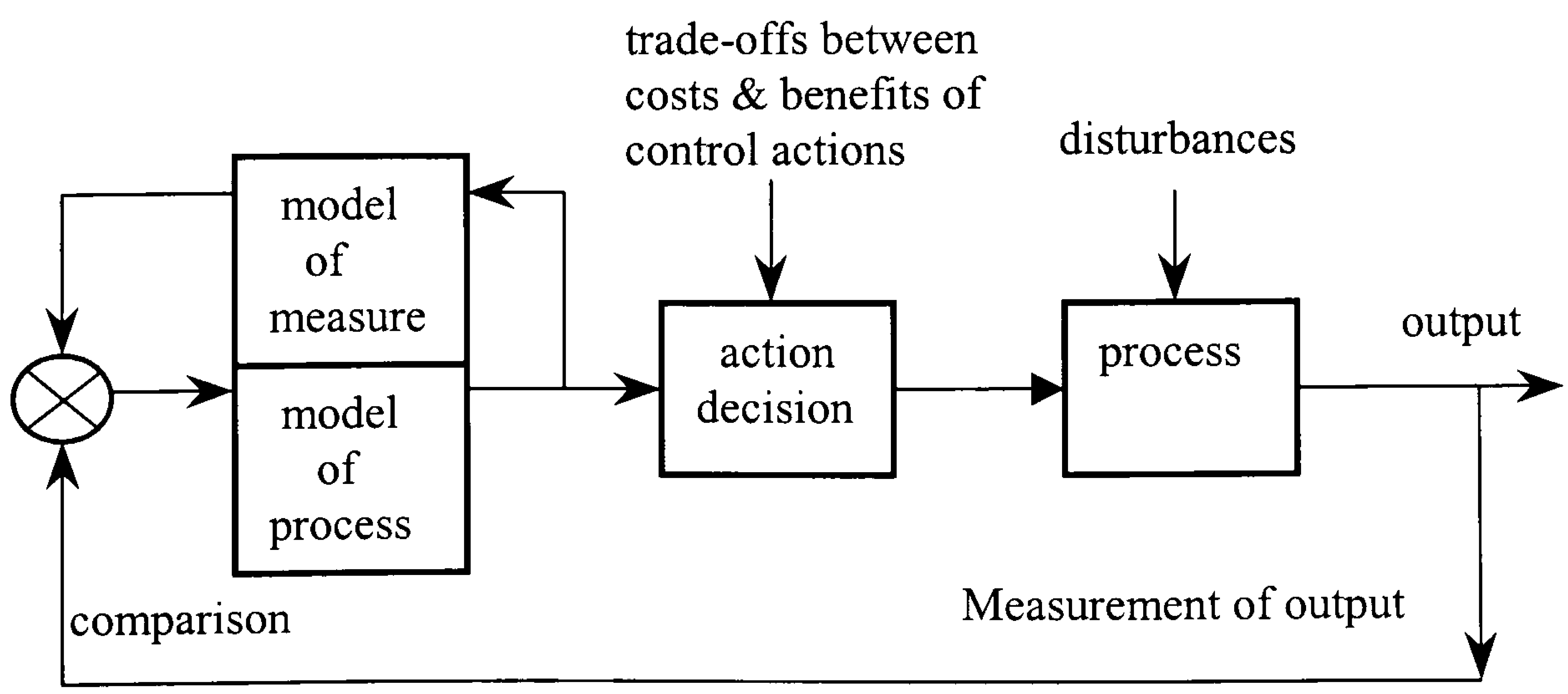


Figures 3.4 The Formal System Model (from Fortune and Peters[85])

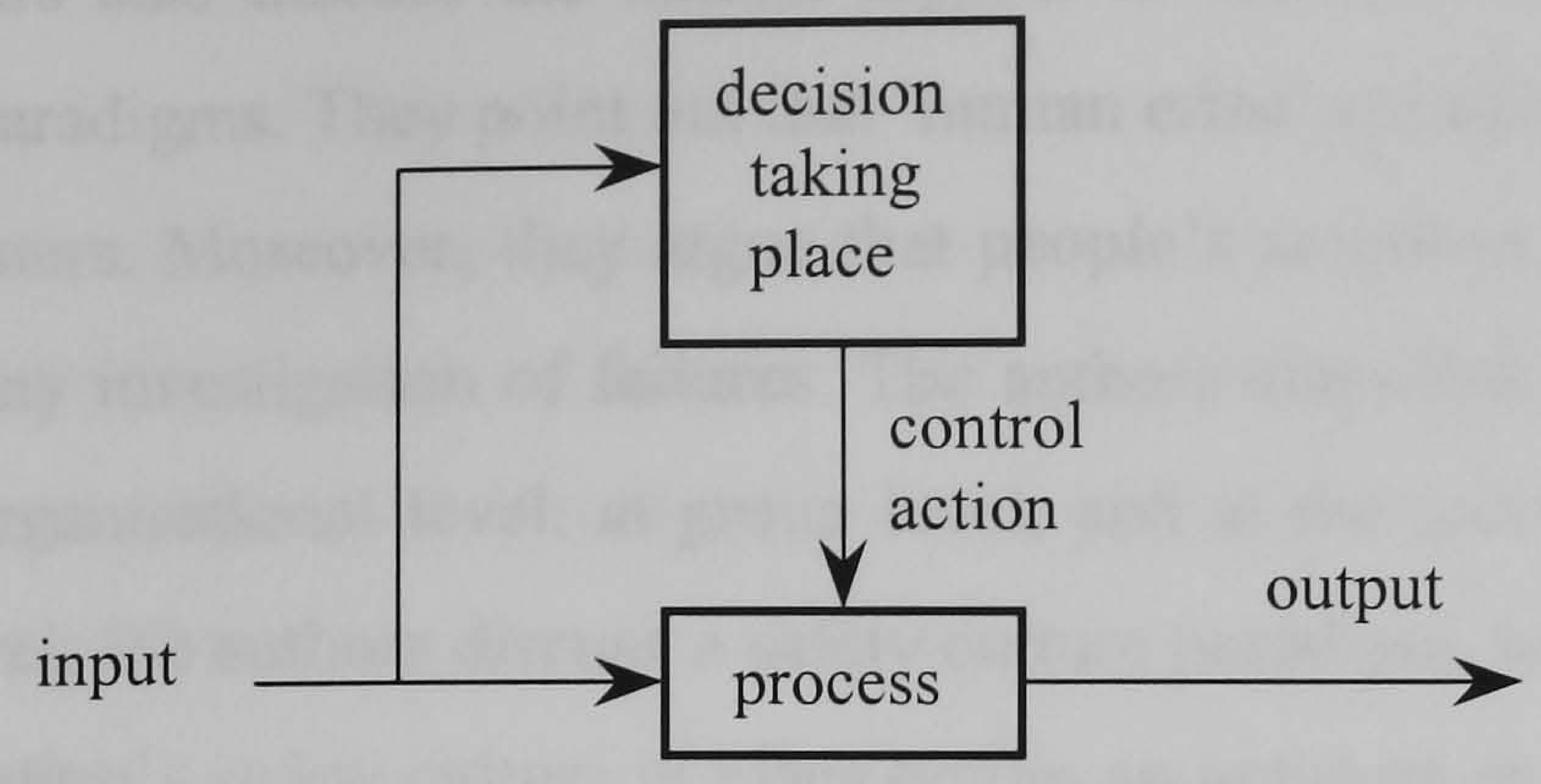
Fortune and Peters describe some paradigms such as the ones embodied in the Control and Communication paradigms. The Control paradigm refers to the norms of behaviour that a system or subsystem applies to its own activities to maintain a desired state. This paradigm employs a classical feedback control, modern feedback control and feedforward control. Figure 3.5(a) shows the classical model which attempts to identify and remove discrepancies between actual and target outputs. A 'modern' feedback control paradigm not only identifies and removes discrepancies between actual and target outputs, but also estimates the true current state and possible effects of any change. The estimation process is accomplished within the control system itself, using a model of the system as shown in Figure 3.5 (b). The internal model of the process of Figure 3.5 (b) evaluates the various control actions which could be taken in order to examine the trade-off between each action's effectiveness and the cost associated with it. Finally, Figure 3.5 (c) shows the feedforward control model; the purpose of this control model is to identify and anticipate disturbances so that decisions can be made before they affect output.



(a) Classical feedback control



(b) Modern feedback Control



(c) Feedforward Control

Figure 3.5 Control Paradigms (from Fortune and Peters[85])

Besides control aspects, communication represents a central role in the FSM. Figure 3.4 illustrates different links of communications such as that between the system and its environment, information flow from the wider system to the subsystem and vice-versa. It also includes other communication links within the system and the subsystems. If any of these links is missing or inadequate when comparing with the FSM then a more specialised communication paradigm is needed. Figure 3.6 shows a dynamic two-way process of communication in which the sender's message can be used to modify subsequent messages. It should be noted that this model is concerned only with the transmission and receipt of information and does not consider other factors such as human aspects (values, beliefs) that may be of great importance in the study of failures. To deal with this issue a communication model within and amongst teams is integrated in the FPM methodology.

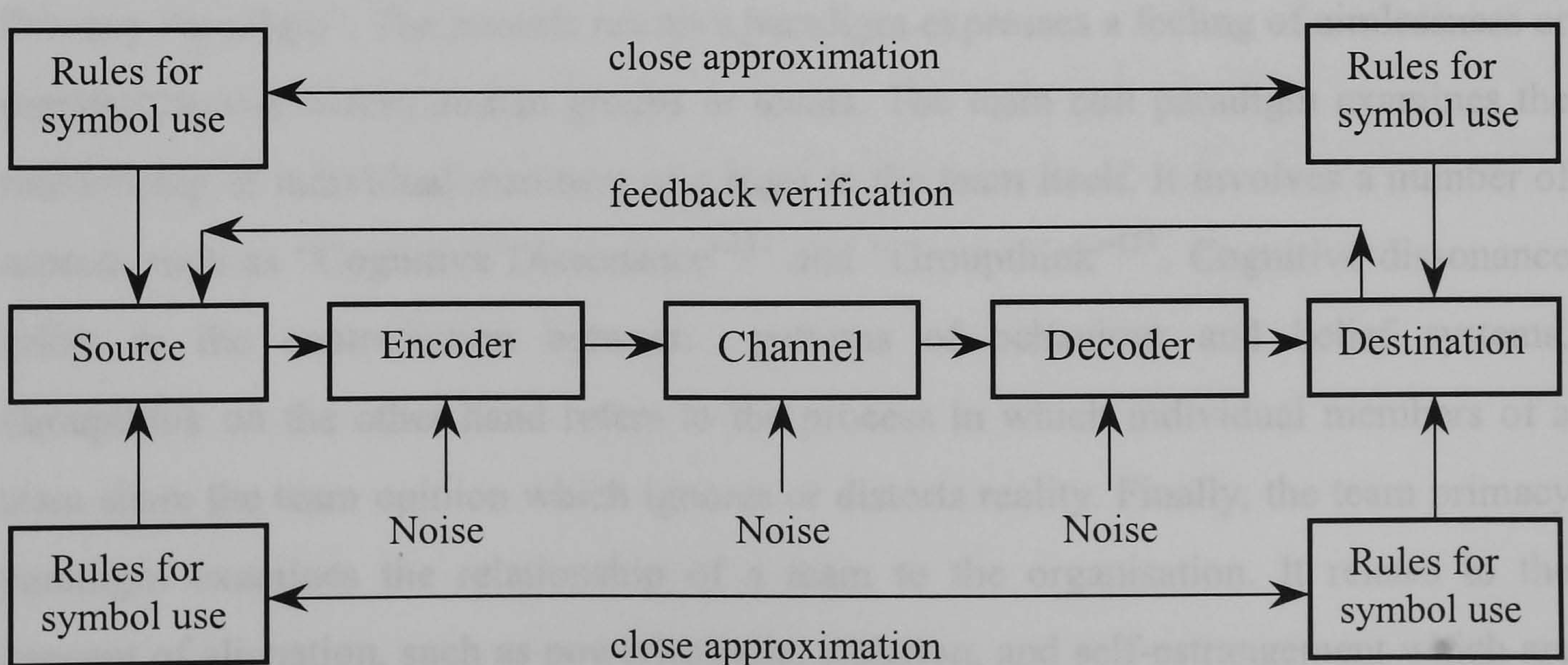


Figure 3.6 Communication Paradigm (from Fortune and Peters[85])

Fortune and Peters also discuss the human aspects of the FSM and the control and communication paradigms. They point out that 'human error' appears in many reports of accidents or disasters. Moreover, they argue that people's activities and decisions have to be central to any investigation of failures. The authors classified human factors into three levels: at organisational level, at group level, and at the individual level. At the organisational level, the authors discuss a safety culture paradigm, which can be used to assess an organisation's safety culture in place before an accident or disaster. The safety culture paradigm suggested by Fortune and Peters contained the below characteristics:

- *an organisation that takes a positive attitude towards criticism and other feedback from lower levels within it and from outside;*
- *an organisation that takes into account the boundaries and patterns of communication within it when designing processes, procedures and working practices;*
- *an organisation that promotes concern for the consequences of its activities and for the effects of individual actions;*
- *an organisation that encourages involvement and commitment and is able to resolve conflict without causing alienation.*

Fortune and Peters describe team behaviour paradigms in order to gain an understanding of human factors at group level. These paradigms are related to undesirable behaviour of teams, which can be new, functioning normally, and well established and have been operating for a period of time. Three main paradigms are described by the authors; they are the "Anomic Reactive Paradigm", the "Team Cult Paradigm", and the "Team Primacy Paradigm". The anomic reactive paradigm expresses a feeling of aimlessness or purposelessness within human groups or teams. The team cult paradigm examines the relationship of individual members of a team to the team itself. It involves a number of aspects such as "Cognitive Dissonance"[151] and "Groupthink"[151]. Cognitive dissonance refers to the contradiction between patterns of behaviour and belief systems. Groupthink on the other hand refers to the process in which individual members of a team share the team opinion which ignores or distorts reality. Finally, the team primacy paradigm examines the relationship of a team to the organisation. It relates to the concept of alienation, such as powerlessness, isolation, and self-estrangement which are combined with other concepts related to alienation.

Human aspects of control and communication are examined by fortune and Peters to address human factors at the individual level. This paradigm examines the interaction between individuals and highly automated systems whereby an operator may be exposed and unable to cope with unexpected events. Fortune and Peters argue that a better way of providing operators a better understanding of processes is:

- *to incorporate predictive displays into control panels;*
- *to include models of the processes in the control systems so as to allow operators to input sample values of key parameters and see whether the values predicted by the models correspond with those measured by the instrumentation;*
- *to design control systems so that they fit 'models' of the systems held by the operators.*

It is emphasised by the authors that there are many other aspects to the individuals' factors, such as communication skills and ability to listen and to tell, in communication and control. However, they stressed that the three levels of organisation, group and individual provide a framework within which possible flaws in communication can be understood.

3.4 Conclusion

This chapter has presented two systemic approaches which were adopted to construct a FSMS model. First, the Viable System Model (VSM) was described. Some key features of the structural organisation of the VSM were given, as well as key characteristics of the VSM and its environment, communication and control. Finally, the Failure Paradigm Method (FPM) was presented. This description included some paradigms such as the Formal System Model, communication and control, and human factors. Chapter five describes how these two systems approaches were used to construct first, an FSMS prototype, and then a final FSMS model.

Chapter Four

A Fire Safety Management System Prototype

4.1 Introduction

Chapter one highlighted the need for a systemic approach to managing fire safety in a coherent way. Chapters two and three have established the theoretical basis for constructing an FSMS. A systemic approach has been adopted to construct the FSMS prototype. It has been applied to the case of an oil and gas offshore organisation. The FSMS is intended to maintain the fire risk within an acceptable range in an oil and gas organisation's operations. This chapter presents an exposition of the developed FSMS prototype. Fire safety and its context in offshore platforms are discussed in section 4.2. A detailed description of individual subsystems of the FSMS is given in section 4.3. Section 4.4 presents some vulnerabilities and strengths of the developed FSMS prototype. It also presents some suggestions for further development of the FSMS prototype in order to obtain an effective or robust FSMS model. Finally, section 4.5 summarises this chapter.

4.2 Offshore Fire Safety and Its Context

Fire risk is inevitably present in any industrial process involving hydrocarbons, including offshore installations. An accident caused by fire may lead to the total loss of an offshore installation, as well as human life. Offshore platforms are usually designed in an extremely compact layout, which has a high density of equipment. As a consequence of this compact layout, not only the direct effect of fire to human life is important, but its impact on the installation itself. An offshore platform has many constraints on weight and space. High pressure systems, quantities of potentially explosive and flammable materials, large equipment, living quarters for the work force, all share the same space. This requires an oil and gas organisation to take measures to improve not only its fire safety performance, but also to improve its operations performance. Over recent years, several approaches have been developed and implemented with the aim of improving the organisation's fire safety performance. For example, 'inherent safety' principles have been applied to the conceptual and detailed design of an offshore platform[144,145]. This approach has the advantage that it addresses the source of fire hazards. However, human and organisational factors remain as important issues to manage fire safety. An FSMS needs to be considered as part of an offshore platform design process, from conceptual design through to commissioning, construction, operation, and decommissioning. The FSMS should not be a 'bolt-on'.

Human factors may be a major source of not only fire accidents, but poor performance of an offshore organisation's operation. Safety literature shows that most accidents and failures may be attributable to some form of human factor. As discussed in chapters one and two, these failures can be characterised as 'apparent' failures and 'latent' failures. Apparent failures are those failures which immediately precede an accident, whilst latent failures are understood as organisational failures committed in design, management, communication, maintenance, etc. From a systemic point of view, addressing technical and human factors is clearly as important as focusing on apparent and latent causes of accidents. Organisations still tend to address these factors in isolation; thus significant reduction of accident rates is still a far reaching objective. If an initial accident should occur, human action is of vital importance in mitigating the effects of a given occurrence by taking effective remedial measures. However, very often a given situation is made worse by taking incorrect actions. Similarly, the likelihood of successful evacuation, escape and rescue operations would in many cases be greatly affected by the human performance concerned. This suggests that human and organisational factors must be adequately considered in fire safety management of offshore operations.

Offshore production plants are complex systems that are continually changing. This is in response to organisations' market requirements, the need to be more competitive, the need to respond to competitive organisations, government legislation, social organisations, etc. Some of these changes involve changes in production processes, technology and personnel. Managing changes in an offshore production process is of critical importance in managing fire safety. In other words, to manage changes is the recognition that changes in process technology potentially invalidate prior fire risk assessment; all process technology changes require re-assessment. Additionally, facilities or process changes invalidate prior fire risk assessment, because they can create new hazards. Moreover, foreseen and unforeseen changes should be considered in the management of fire safety. Otherwise they can lead, and have led, to catastrophic events. This suggests the need for an effective system capable of integrating technical and human factors, 'apparent' and 'latent' factors, and foreseen and unforeseen events in order to manage fire safety offshore.

4.2.1 Types of Offshore Installations

This section summarises different types of offshore installations for a typical oil and gas organisation. The type of offshore installation will depend on whether it is used in the search for oil or for production, or whether it is required to provide support to these operations. Three types of offshore installations can be distinguished: exploration platforms, drilling platforms and production platforms. A brief description of these platforms is given below.

Exploration Platforms

In general, three types of exploration platforms can be found for oil exploration offshore. They are the jackup rig, the semi-submersible, and the self-positioning drillship. The jackup rig is a floating platform which can be either self-propelled or towed from one location to another. On reaching the location the legs are lowered until they reach the sea bed, and the platform jacks itself up clear of the water so that it cannot be affected by high seas. This type of installation can be used for shallower depths of exploration at around 300 ft. A semi-submersible platform, on the other hand, is used for deeper water, up to about 3000 ft. This platform can be self-propelled or towed to a location and is maintained on station by anchors or by dynamic positioning equipment. When a semi-submersible is moved, water is pumped out of buoyancy chambers located in the 'pontoon' feet, which causes the vessel to rise and float on the surface as a normal ship. A self-positioning drillship is a more recent development for exploration. This unit is used for exploration in depths greater than 3000 ft. They are self-propelled at normal ship speeds and can carry considerable deck load making them extremely versatile.

Production Platforms

Once the hydrocarbons have been discovered by means of any of the exploration platforms, and the field has proved to be commercial, consideration is given to the type of platform which will be installed. A production platform traditionally houses both the production process facility and the drilling equipment. A production facility is used to separate the hydrocarbon product coming from the well, this product is a mixture of oil, water and gas. The water and gas are separated from oil. The gas may also be treated before it can be exported to shore or used as a fuel on the platform itself. A drilling facility, on the other hand, is required to bore the production wells, and house the metering and control systems to monitor the flow of oil from the wells. Two types of fixed production platform are predominant in the production of oil and gas. They are the concrete gravity platform and the steel jacket platform.

A typical concrete gravity platform consists of a base unit compartment to form a storage tank. It has a number of legs, perhaps three or four depending on design but sometimes a single column takes the height of the structure above water level. The deck and various modules are placed on top of the legs. Drilling is carried out through one or more of the hollow legs or the central column and the produced oil can be stored ready for export. In order to maintain sufficient weight to keep it in position, the storage tanks for the platform must be kept filled with either water or oil. A fixed platform typically consists of a substructure and a superstructure. A substructure consists of a steel tubular jacket with tubular legs held together by welded tubular bracing, the whole being securely piled to the sea bed through tubes attached to the bottom of the legs. There are also various vertical tubes required for obtaining sea water for platform utilities, for the protection of sub-sea electrical cabling, and as a guide for well risers. The superstructure usually consists of a deck assembly, which supports all the prefabricated facilities for different processes. It also supports the drilling equipment, a power generation equipment, utilities, living accommodation modules, communication facilities, cranes, etc. that make up the topsides of the platform.

A Typical Oil and Gas Offshore Production Platform

For the purpose of this study a typical fixed production platform has been selected to model an FSMS prototype. Fixed production facilities vary from a simple separation and disposal system to a highly complex processing plant utilising interconnected pipe work, dozens of process vessels and a great amount of equipment and machinery. Figure 4.1 shows the typical processes that can be found in most offshore production platforms.

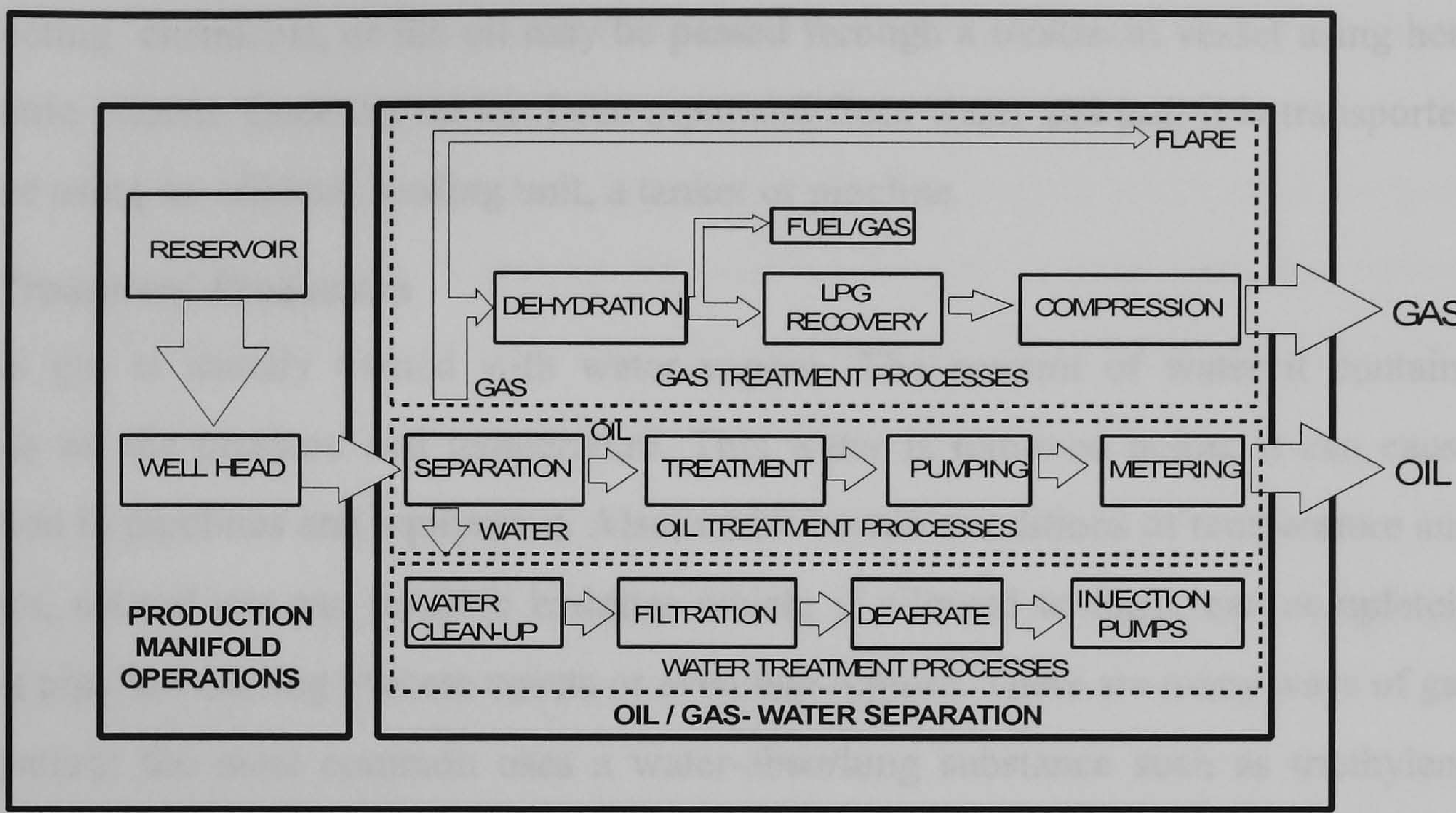


Figure 4.1 Typical Processes in an Offshore Production Platform

Inlet Manifolds

As the reservoir fluids flowing up the tubing from the individual wells reach the surface, the total oil production must be gathered before processing. In order to achieve this, each well is connected to one or more inlet manifolds, which are large diameter production header pipes connected to smaller diameter flow lines. Then each header carries its share of total production to the first stage of the production process system, the separation of the well products.

Separation Processes

An oil well produces oil, gas, condensate and water in varying proportions. The main function of a production platform is to separate these individual components from the mixture of oil and gas and water. Separation is based on the principle that oil, water and gas all have different densities, although modern separators contain internal devices which consist of natural separation processes. Segregation of the elements takes place over a number of phases. In two stage separation the gas only is liberated from the liquid and in three stage separation the gas is first liberated from the liquid, then the liquid itself separated into oil and water.

Oil Treatment Processes

After separation the oil is free from water and dissolved gas, but may still contain water as an emulsion. It is necessary to eliminate the water otherwise it would cause corrosion in the pipelines and be unacceptable as feedstock in the refinery. This can be achieved by injecting chemicals, or the oil may be passed through a treatment vessel using heat or electric current. Once the oil has been separated from water and gas, it is transported onshore using an offshore loading unit, a tanker or pipeline.

Gas Treatment Processes

Natural gas is usually treated with water vapour. The amount of water it contains depends on the pressure and temperature. This water is removed before it can cause corrosion in pipelines and equipment. Also, under certain conditions of temperature and pressure, natural gas can produce hydrates which, if allowed to form, can completely block a pipeline causing process upsets or even line rupture. There are many ways of gas dehydration; the most common uses a water-absorbing substance such as triethylene glycol through which the gas is passed within an absorption tower. As the gas is bubbled through the glycol, water is absorbed and the mixture is passed to a separate regeneration unit which is heated to drive off the absorbed water, after which glycol can be re-used. It is common practice to burn off natural gas through the flare stack of the platform. This waste of energy has now been regulated in many countries as a result of an increase in environmental concerns, though some gas is still flared off for safety reasons.

Water Injection System

In order to maintain pressure in the well, water is injected into the water zone of the reservoir. Sea water is primarily used for this purpose, though it must be tested and treated. Oxygen, which occurs naturally in sea water, is very corrosive and must also be removed. This can be achieved by using mechanical methods. The de-aeration towers used in the mechanical process are usually vacuum-based when the reduction in pressure inside the column causes the dissolved oxygen to be liberated. The water is injected either into an existing production well which is no longer producing, or into a drilled injection well, the bottom of which is in the water zone of the reservoir.

Thus far in chapter 4 has been discussed fire safety in the context of offshore platforms, as well as some relevant aspects of these installations. An FSMS prototype has been constructed for a typical oil and gas production facility. A detailed description of this prototype is provided in the following section.

4.3 Description of the FSMS Prototype

This section presents the developed FSMS prototype for a typical oil and gas offshore production platform. The approach taken to construct this prototype was to use the VSM, which was described in chapter three. First, is developed the purpose for a typical oil and gas organisation in terms of fire safety. Second, is described the various operations of the offshore platform that deal directly with the oil and gas production activities. Finally, a detailed description of the prototype is given.

4.3.1 A typical Oil and Gas Organisation and Its Activities

Regarding safety of a typical oil and gas organisation, a purpose for the FSMS prototype was formulated. The formulated FSMS's purpose says as follows:

To maintain the fire risk within an acceptable range, for an oil and gas organisation.

The formulated purpose helped to identify those operations that deal directly with the activities of an oil and gas organisation within which the organisation's safety and fire safety policy must be implemented. In addition to the formulated purpose, the principle of recursion of the VSM was used to identify major activities of the organisation and construct the organisational structure of the FSMS prototype. According to Stafford Beer,[81,82,83] "in a recursive organisational structure, any viable system contains, and is contained in a viable system". It is possible then to depict an organisation as a set of viable systems contained within a set of viable systems, and so on, as illustrated in Figure 4.2. At the recursion level one, for example, the HSE may contain several divisions, such as oil and gas industry (Offshore Safety Division), transport industry, power generation industry and so on (only the Offshore Safety Division is shown). At the second recursion level, the oil and gas industry may contain various oil and gas companies (only one company is shown). At the third level of recursion, a typical oil and gas organisation may contain various operations, such as exploration, production, and oil and gas treatment operations. Regarding fire safety in a typical oil and gas organisation, the viable systems become fire safety in exploration, fire safety in production, fire safety in oil and gas treatment, as shown in Figure 4.2.

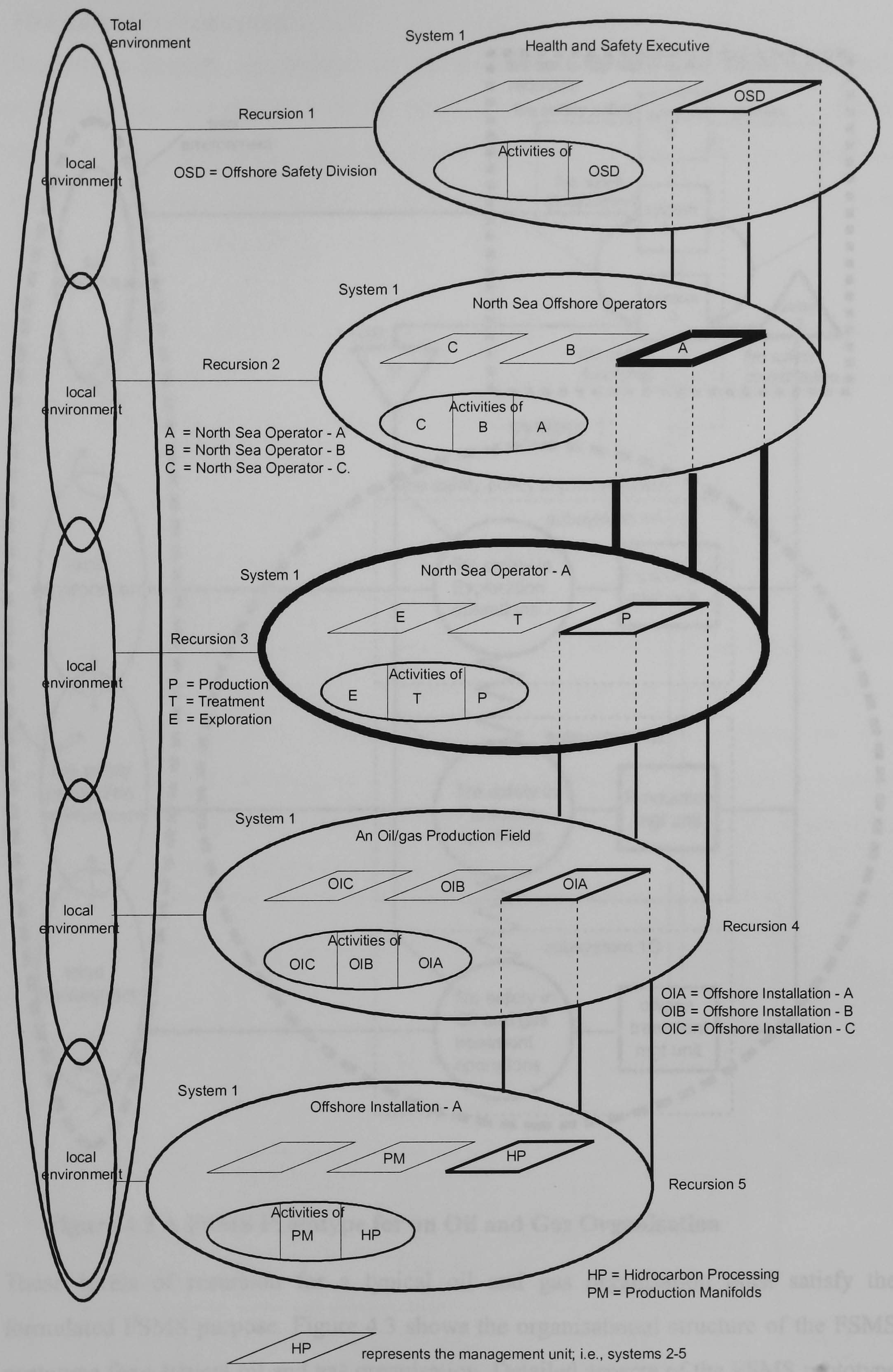


Figure 4.2 Multiple Recursion for an Oil & Gas Organisation

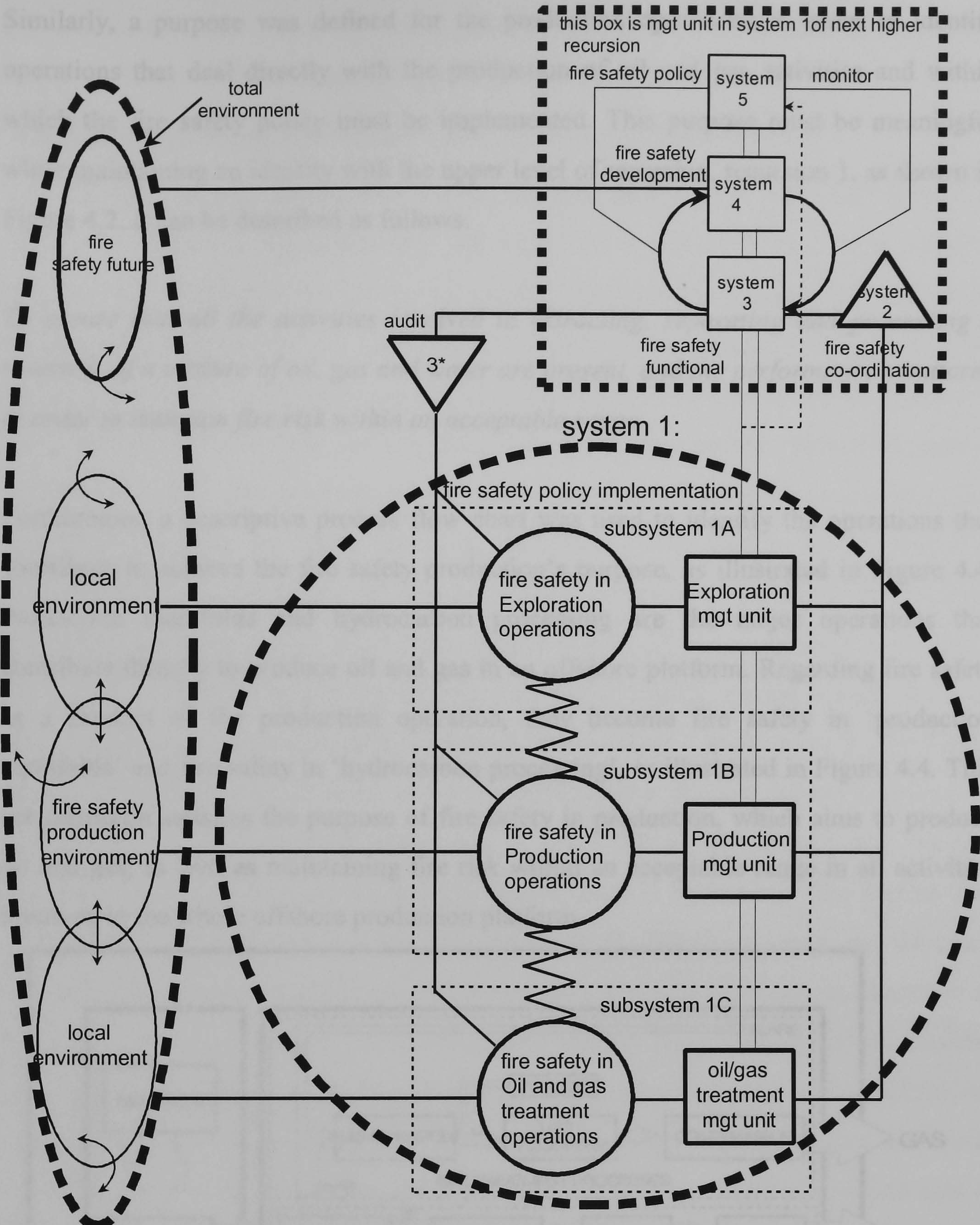


Figure 4.3 A FSMS Prototype for an Oil and Gas Organisation

These levels of recursion for a typical oil and gas organisation must satisfy the formulated FSMS purpose. Figure 4.3 shows the organisational structure of the FSMS prototype for a typical oil and gas organisation. Detailed aspects of the FSMS prototype for the production operations are given below.

Fire Safety in Production

Similarly, a purpose was defined for the production operations in order to identify operations that deal directly with the production of oil and gas activities and within which the fire safety policy must be implemented. This purpose must be meaningful while maintaining an identity with the upper level of recursion, recursion 1, as shown in Figure 4.2. It can be described as follows:

To ensure that all the activities involved in extracting, separating and processing a reservoir of a mixture of oil, gas and water are present, and the performance monitored in order to maintain fire risk within an acceptable range.

Furthermore, a descriptive process flow chart was used to identify the operations that contribute to achieve the fire safety production's purpose, as illustrated in Figure 4.4. Production manifolds and hydrocarbon processing are the major operations that contribute directly to produce oil and gas in an offshore platform. Regarding fire safety as a product of the production operation, they become fire safety in 'production manifolds' and fire safety in 'hydrocarbon processing', as illustrated in Figure 4.4. This consideration satisfies the purpose of fire safety in production, which aims to produce oil and gas, as well as maintaining fire risk within an acceptable range in all activities involved in the whole offshore production platform.

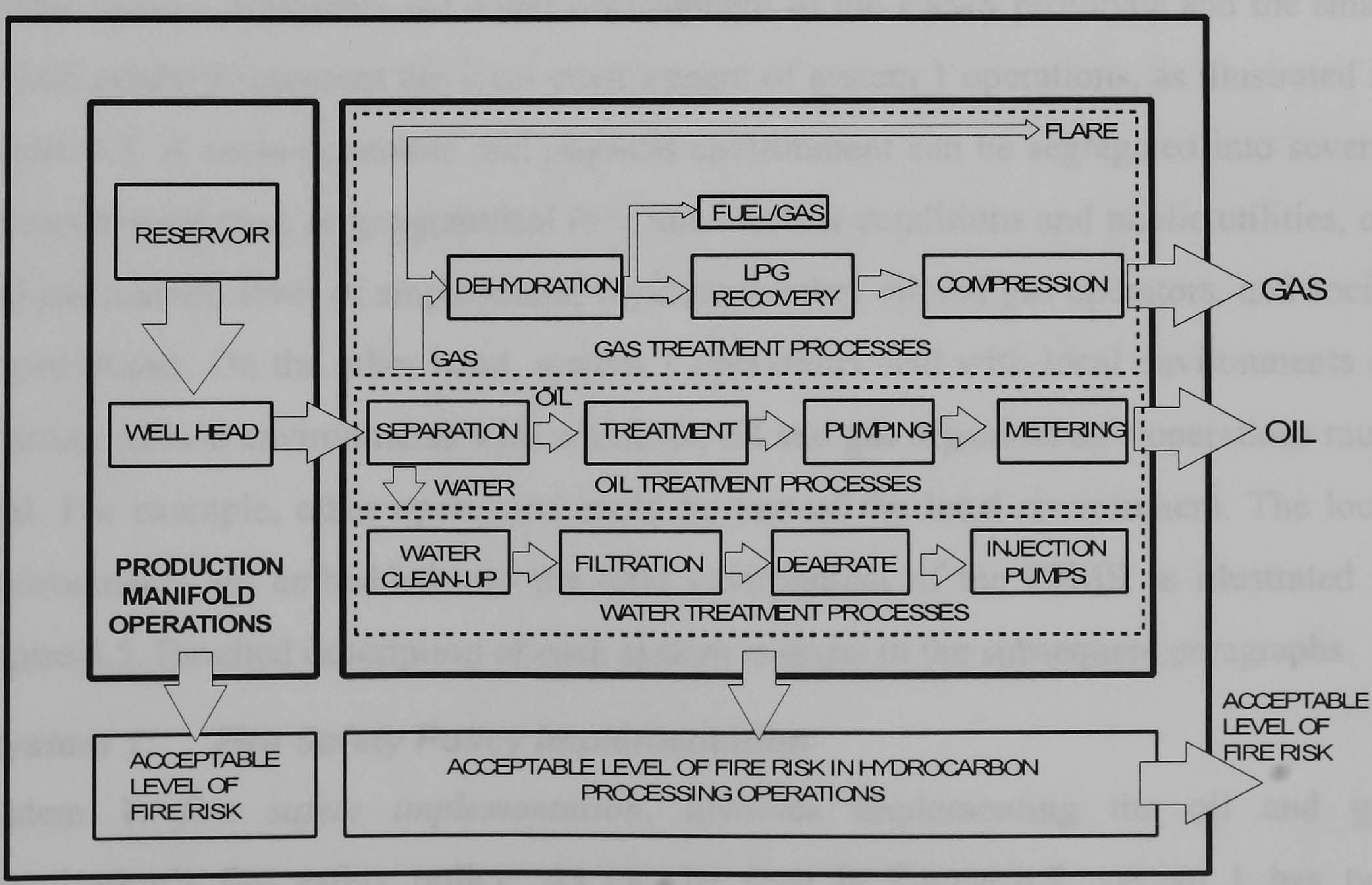


Figure 4.4 Flow Diagram for an Oil & Gas Production Offshore

It should be emphasised that all activities, such as engineering, maintenance, loss prevention, etc., not included in the process flow chart are regarded as supportive activities. They will all form part of the FSMS prototype as described below.

4.3.2 A FSMS Prototype for an Offshore Production Platform

The FSMS prototype developed in this research project and described here is a conceptual approach for addressing fire safety in a coherent way. This systemic approach to fire safety is intended to be an effective system to maintain fire risk within an acceptable range in oil and gas offshore installations. In essence, it is a systemic set of five inter-related subsystems associated with systems 1 to 5, as shown in Figure 4.5. First, system 5 deals with the organisation's fire safety policy. Second, system 4 involves fire safety development, which identifies strengths, weaknesses, opportunities, and threats regarding fire safety. Third, system 3 involves maintaining fire risk within an acceptable range in the whole oil and gas production offshore operation. System three also deals with sporadic fire safety audit through system 3*. Four, system 2 co-ordinates the activities achieved by the operations of system 1. Finally, system 1 deals with the implementation of fire safety policy received from system 3 and system 2. The FSMS prototype interacts with its local and wider environment through system 1 operations and system 4. Environment is understood as being the socio-economic and physical infrastructure into which an oil and gas organisation is embedded. The broken line elliptic symbol represents the wider environment of the FSMS prototype and the small elliptic symbols represent the local environment of system 1 operations, as illustrated in Figure 4.5. A socio-economic and physical environment can be segregated into several characteristics, such as geographical location, weather conditions and public utilities, oil and gas market, level of employment, regulators, other oil and gas operators, and social organisations. On the other hand, system 1 operations deal with local environments or institutionalised environments with which the oil and gas organisation's operations must deal. For example, other operations could be part of the local environment. The local environments are embedded into the total environment of the FSMS as illustrated in Figure 4.5. Detailed description of each system is given in the subsequent paragraphs.

System 1: Fire Safety Policy Implementation

System 1, *fire safety implementation*, involves implementing the oil and gas organisation's fire safety policy. As can be seen in Figure 4.5, system 1 has two operations, namely fire safety in 'production manifolds' and fire safety in 'hydrocarbon processing'. A common purpose that is consistent with the purpose of the fire safety in production was defined for these two operations as follows:

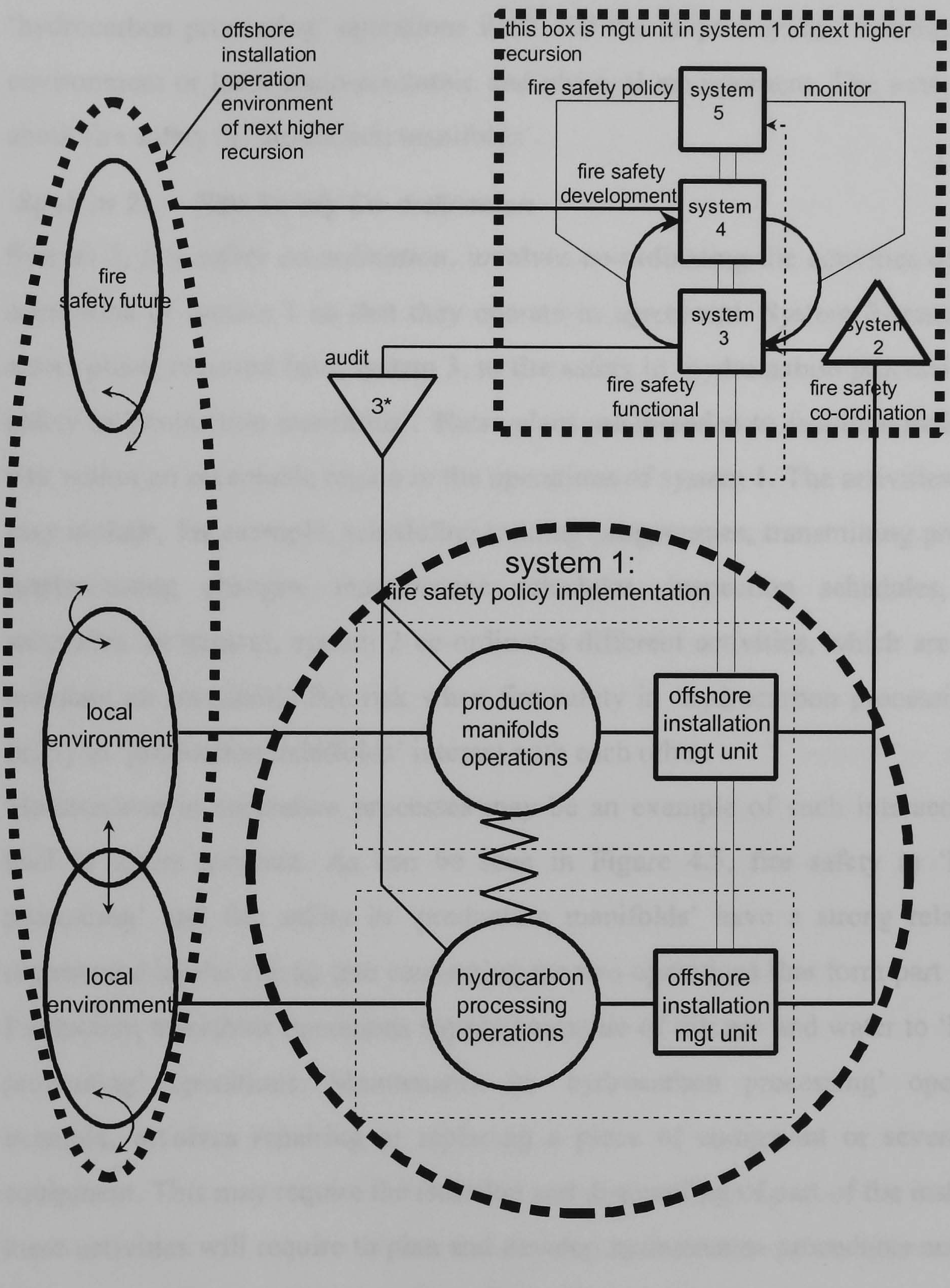


Figure 4.5 A FSMS Prototype for a Production Offshore Platform

to maintain fire risk within acceptable range in all activities involved in the 'production manifolds' and 'hydrocarbon processing' operations throughout the installation life cycle, from design to decommissioning.

Figure 4.5 shows the fire safety in 'hydrocarbon processing', which is a viable system in its own right. This means that the whole FSMS prototype for the oil and gas offshore production platform is replicated in each operation of system 1. The square box represents the management, which embodies the systems 2 to 5, the circle is the 'hydrocarbon processing' operations itself and the elliptic symbol represents the local environment or local socio-economic and physical environment. The same can be said about fire safety in 'production manifolds'.

System 2: Fire Safety Co-ordination

System 2, *fire safety co-ordination*, involves co-ordinating the activities of the various operations of system 1 so that they operate in agreement. System 2 transmits all fire safety plans, received from system 3, to fire safety in 'hydrocarbon processing', and fire safety in 'production manifolds'. These plans are intended to facilitate maintaining fire risk within an acceptable region in the operations of system 1. The activities of system 2 may include, for example, scheduling training programmes, transmitting procedures for implementing changes, maintenance schedules, inspection schedules, and audit schedules. In general, system 2 co-ordinates different activities, which are intended to maintain an acceptable fire risk when fire safety in 'hydrocarbon processing' and fire safety in 'production manifolds' interact with each other.

Maintenance in separation processes may be an example of such interaction that can lead to a fire incident. As can be seen in Figure 4.5, fire safety in 'hydrocarbon processing' and fire safety in 'production manifolds' have a strong relationship, as represented by the zigzag line connecting the two operations that form part of system 1. Production manifolds operations supply a mixture of oil, gas and water to 'hydrocarbon processing' operations. Maintenance in 'hydrocarbon processing' operations, for example, involves repairing or replacing a piece of equipment or several pieces of equipment. This may require the isolation and dismantling of part of the installation. All these activities will require to plan and develop maintenance procedures and schedules. Otherwise, this may cause serious fire safety problems, such as over-pressure in equipment in 'hydrocarbon processing' operations, because of the continuous supply of a mixture of oil and gas-water from 'production manifolds' operations. This may also cause fire safety problems in 'production manifolds' operations. Maintenance schedules have to be agreed by both fire safety in 'production manifolds' and fire safety in 'hydrocarbon processing' managers in order to prevent such possible fire safety problems.

In summary, system 2 involves co-ordinating all activities conducted by the operations of system 1. The main purpose of System 2 is to prevent possible fire safety problems arising from the interaction of systems 1 operations. It accomplishes its function in a continuous never-ending loop.

System 3: Fire Safety Functional

System 3, *fire safety functional*, involves ensuring that system 1 implements the oil and gas offshore organisation's fire safety policy, as well as ensuring that fire risk is maintained within an acceptable range. The activities in system 3 are achieved by the oil and gas organisations' functional areas, referred to here as the fire safety operations directorate. The fire safety operations directorate may consist, in part, of the Offshore Installation Manager (OIM), Production Support Manager, Project Manager, Engineering, Loss Prevention, Planning and Programming, Maintenance and Technical Support, and Inspectors. There are three kinds of information that system 3 has to handle in order to accomplish its function. First, it deals with fire safety information which flows through the vertical command channel down from systems 5 and 4. Second, it deals with fire safety information which flows from system 2 to system 3. Finally, it deals with fire safety information that flows through the audit channel from system 1 to 3. Additionally, it communicates the organisation's strengths and weaknesses to system 4 to achieve the objective of maintaining an acceptable level of fire risk in system 1 operations.

System 3 transmits the organisation's fire safety policy and any special instructions, which are developed by system 4 and deliberated by system 5, to system 1 through the vertical channel. It also allocates the necessary resources required to implement the organisation's fire safety policy. System 1 reports whether the organisation's fire safety policy is being accomplished or not to system 3 through the same vertical channel. This information flow is also a continuous process that should be conducted on a day-to-day basis with system 1. System 3 transmits its short-term fire safety plans to system 1 through system 2. It also requires system 2 to report all conflicting aspects arising from system 1 operations in order to develop new action plans. This information flow is also conducted on a daily basis. Finally, system 3 provides an essential channel for the sporadic audit of the system 1 operations. The audit process is achieved in agreement with system 1, and conducted by system 3*.

System 3*: Fire Safety Audit

System 3*, *fire safety audit*, is part of system 3 and its function is to conduct sporadic audits into the operations of system 1. The audit process must cover a thorough examination of the safety performance of humans, equipment, processes and installations, as well as human injuries caused by fire incidents. System 3* intervenes in system 1 operations in agreement with system 1. It should be noted that auditing is distinct from monitoring as used by some existing SMSs. Unannounced auditing, although at agreed frequencies, should be conducted to verify whether the established fire safety plans are being met or not. Furthermore, auditing fire safety must be conducted additionally by an external auditor, such as HSE. Reports from external audits may provide important feedback, which would enable system 3 to maintain and develop its capability to manage and maintain an acceptable fire risk.

System 4: Fire Safety Development

System 4, *fire safety development*, is responsible for fire safety development for the whole organisation. Considering strengths, weaknesses, threats, and opportunities from the organisation's wider and local environment, system 4 can suggest changes to the organisation's fire safety policies. This means that system 4 deals with internal needs received from system 3, as well as dealing with external requirements, which are reflected in the organisation's wider environment. Internal requirements may include, for example, developing new training techniques, developing new maintenance procedures, developing new operations procedures, and other difficulties experienced by system 1 in its operations in order to accomplish fire safety plans. External requirements may include, for example, compliance with existing regulations and standards, and lessons learnt from fire accidents in other industries. There are several important factors that system 4 needs to consider for the future development of fire safety. These factors may include, for example, the offshore platform design, technological development, human factors, new regulations and standards.

Fire risk involved in an offshore platform life cycle must be considered at the design or redesign stage. It is generally recognised that decisions made at an early design stage have the most significant impact on the platform life cycle. Inherently safer design principles, for example, should be further developed and applied to both new offshore design or integrated into fire safety design for existing offshore platforms. Moreover, the design process of the offshore platform must be an integral part of the FSMS. System 4 should continuously identify potential problems of fire safety throughout the life cycle of the offshore production platform in order to devise and implement the necessary modifications to system 1 operations. Other kinds of developments may relate, for example, to increasing and verifying the reliability of fire safety models. System 4 should deal with all fire safety issues related to human aspects. An oil and gas organisation needs, for example, to establish a strong fire safety culture and to promote fire safety commitment, which should include employees, top and line management. It should also design a comprehensive fire safety training process for all employees at all levels, but particularly focusing on site training, for example, in relation to emergency response. Finally, system 4 should pay attention to new and emerging regulations and international standards that may have a significant impact on the system 1 operations. New or future fire safety regulations should be adopted and implemented in advance.

System 5: Fire Safety Policy

System 5, *fire safety policy,* is responsible for establishing fire safety policies for the whole oil and gas organisation, as well as monitoring the internal and external requirements, as represented by the needs of system 3 and system 4 respectively. This monitoring process is represented by the lines that connect the loop between systems 3 and 4 as shown in Figure 4.5. System 4 develops choices, such as those associated with the key factors discussed above; system 5 should deliberate and make feasible decisions to deploy strategic fire safety plans. It should elucidate responsibilities and roles of the main players and bodies for managing fire safety. The duties of line managers in particular must be identified, and those of employees also made clear. This should create the basis for a strong safety culture.

The FSMS prototype described in this section is a conceptual model, which was built on a systemic approach called VSM. This systemic approach to fire safety offshore is intended to maintain fire risk within an acceptable region in an oil and gas organisation. It was modelled for the case of an oil and gas production offshore installation, though it could be easily extended to incorporate other offshore platforms, or even to consider a whole oil and gas corporation. The FSMS prototype described in this section was mapped to the paradigms of the Failure Paradigm Method (FPM) in order to detect vulnerabilities, and a synthesis developed. The results of this mapping process are discussed below.

4.4 Constructing a FSMS Model

This section presents the results of the mapping process, which highlights some vulnerabilities of the FSMS prototype. The FPM and some of its paradigms were described in section 3.3 of chapter three. It also provides a description of a comparison process used to conduct the mapping. As discussed in chapter one, the aim of the comparison process was to identify vulnerabilities and inconsistencies of the FSMS prototype using systems paradigms, such as the Formal System Model (FSM), communication and control, and human factors. Detailed aspects of the comparison process and discrepancies between the FSMS prototype and the FPM paradigms are given below.

4.4.1 An Inquiry Process

Figure 4.6 shows an adapted methodology that was used to investigate possible deficiencies of the developed FSMS prototype. This inquiry process consists of four complementary stages. The first stage, 'systems set out and assembly', involves selecting appropriate paradigms to be compared with their counterparts of the FSMS prototype. As can be seen in Figure 4.6, four paradigms, i.e., the Formal System Model (FSM), control, communication, and 'human factors', were selected to complete this stage.

The FSMS prototype was described in section 4.3, whilst the FSM, control and communication, and human factors paradigms were described in section 3.3 of chapter three. The second, comparison, stage involves comparing the selected paradigms with their counterpart in the FSMS prototype. In order to complete this stage, the FSM was compared with the structural organisation of the FSMS prototype. Upon the completion of this comparison, the selected paradigms were compared with the control and communication, and 'human factors' aspects embedded in the FSMS prototype. The results of this comparison process are given below. In the third, interpretation, stage of the inquiry process, the discrepancies resulting from the comparison process are analysed in order to determine the strengths and vulnerabilities of the FSMS prototype. The fourth stage, synthesis, draws lessons learnt from the first three stages.

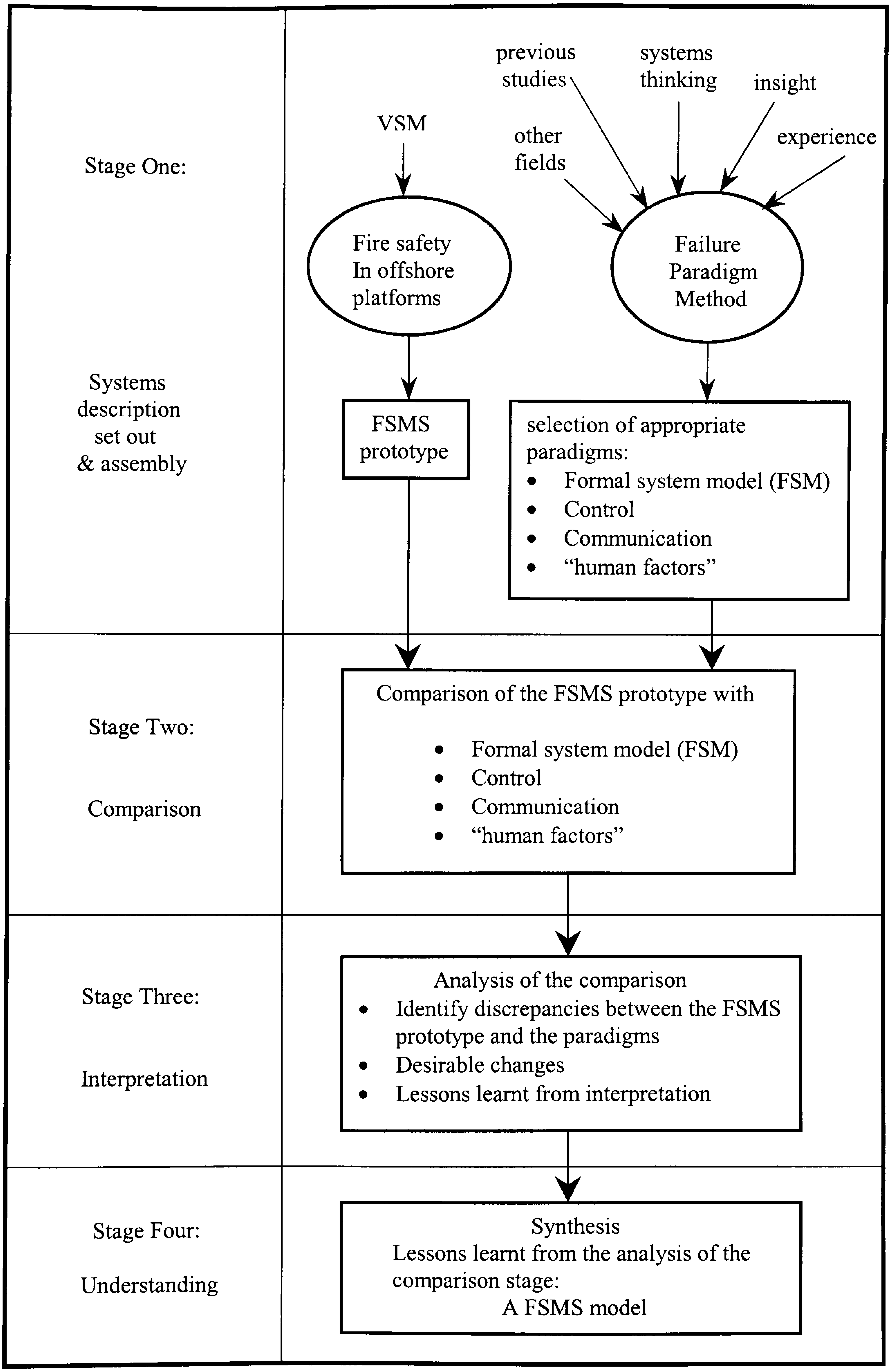


Figure 4.6 An Inquiry Process

A Fire Safety Management System (FSMS) Model has resulted from this inquiry process. The FSMS model is presented in chapter five.

4.4.2 Strengths and Vulnerabilities

This section describes some discrepancies found in the comparison stage of the inquiry process. It first discusses the discrepancies found in the mapping process of the FSM to the FSMS prototype. It continues by presenting the results found in the comparison of the control and communication paradigms with the communication and control aspects of the FSMS prototype. This section concludes by presenting the discrepancies between the human factors paradigms and the human aspects of the FSMS prototype.

The FSM and the Structural Organisation of the FSMS Prototype

Table 4.1 maps the FSM to the structural organisation of the FSMS prototype. Figures 4.7, 4.8 and 4.9 show the structural organisation of the FSMS prototype according to the FSM format. Figure 4.7 shows a higher recursion; Figure 4.8, on the other hand, shows the next recursion below, that is, the structural organisation of the FSMS prototype for an oil and gas production operation. Figure 4.9 shows a lower recursion level of the FSMS prototype.

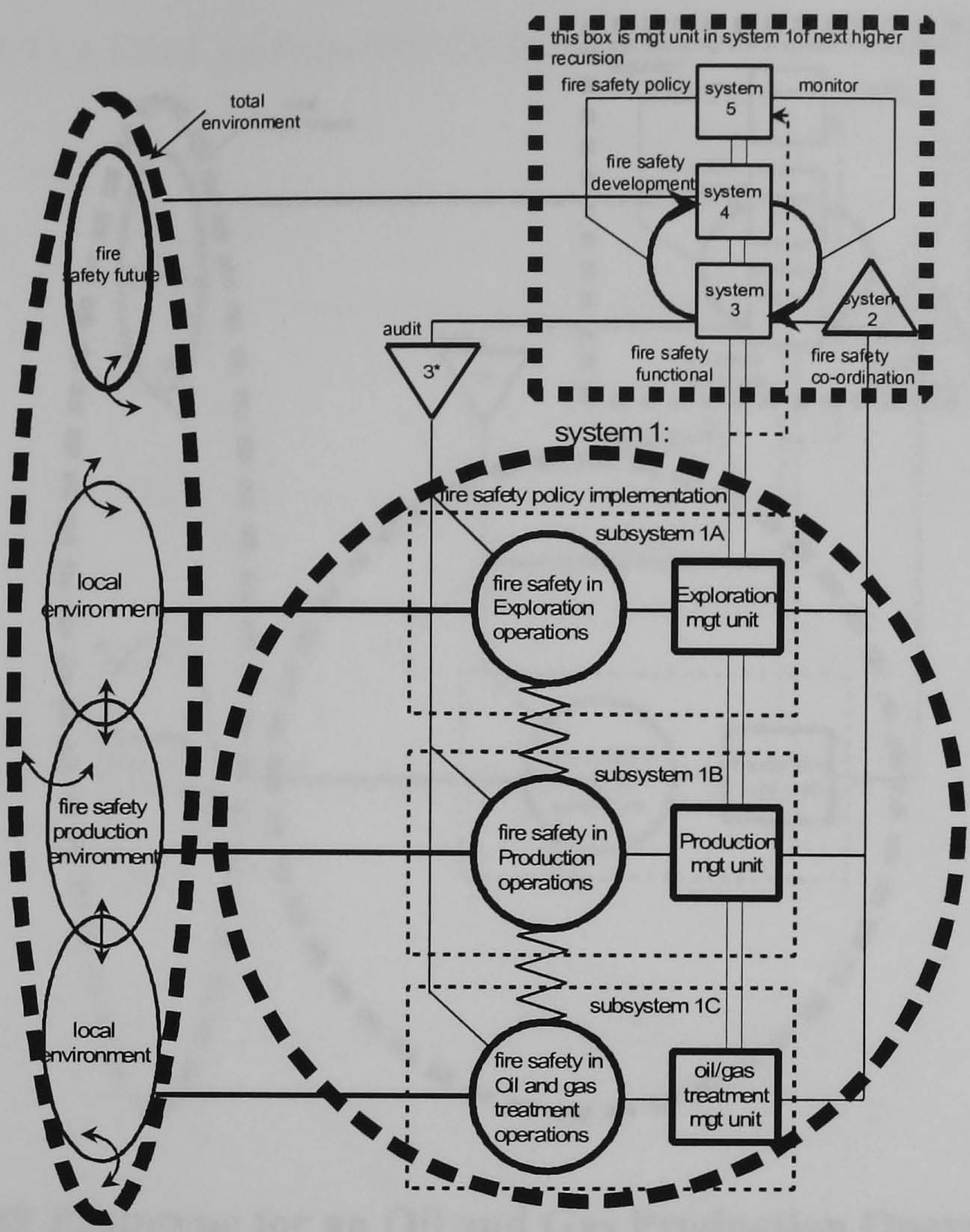
Table 4.1 The FSM And the FSMS Prototype

The Formal System Model (FSM)	The FSMS Prototype
• decision making subsystem	• system 3 and system 5
• subsystems or components that carry out transformations	• system 1
• performance monitoring subsystem	• system 3*
• hierarchical structure and its environment	• recursive structure and its environment

According to Table 4.1, the FSM suggests that the FSMS prototype must have a "decision making subsystem", "subsystems that carry out transformations", and a "performance monitoring subsystem". These subsystems should be arranged in a hierarchical structure which interacts with a wider environment. It does not suggest explicitly the need for a fire safety development subsystem and a fire safety co-ordination subsystem. The FSMS prototype on the other hand has two subsystems, system 3 and system 5, that deal with "decision making". System 1 deals explicitly with implementing the organisation's fire safety policy and system 3* involves auditing the operations of system 1 sporadically. Moreover, the FSMS prototype contains a specific subsystem called fire safety development, which involves identifying threats and opportunities in the oil and gas organisation's environment; it also deals with the organisation's strengths and weaknesses. Considering the organisation's threats and opportunities, weaknesses and strengths, system four, fire safety development, involves planning fire safety for the whole organisation. It should be noted that fire safety development is not part of safety decision making, though it facilitates decision making.

The FSM suggests that there are not interactions among the various subsystems or components that "carry out transformations". This means that the FSM suggests there is no need for taking into consideration the interaction among the various operations that form part of system 1 of the FSMS prototype. For example, as can be seen in Figure 4.9, the FSM suggests that there are no interactions between the fire safety in 'production manifolds' and fire safety in 'hydrocarbon processing'. Because of this, the FSM does not suggest that the FSMS prototype must have a subsystem which can deal with the interaction of the various operations of system 1. The structural organisation of the FSMS prototype, on the other hand, suggests that the interaction among the various operations of system 1 is vital to satisfy and maintain the purpose of the whole organisation regarding fire safety. The FSMS has a function called fire safety co-ordination, system 2, that co-ordinates the internal activities of the various operations that form part of system 1. It should be emphasised that dealing with such interactions is of vital importance in order to maintain fire risk within an acceptable region in the offshore platform operations. Unless these interactions are considered, conflicting aspects may arise from such interactions and these conflicting aspects may lead to incidents or even catastrophic events, such as for example, the Piper Alpha fire. The "Tartan" and the "Claymore" production platforms were still sending oil and gas to the Piper Alpha platform whilst it was on fire. This is a clear evidence of the lack of co-ordination amongst the operations of such installations.

Finally, the FSM suggests that the structural organisation of the FSMS prototype must have a specific "performance monitoring" subsystem. It should be emphasised that the structural organisation of the FSMS prototype does not contain a specific subsystem that monitors the organisation's fire safety performance. It should be also emphasised that the system 3* of the FSMS prototype deals with auditing the fire safety performance of the various operations of system 1. Changes to the structural organisation of the FSMS prototype are discussed in section 4.4.3.



(a) An FSMS Prototype for an Oil and Gas Organisation

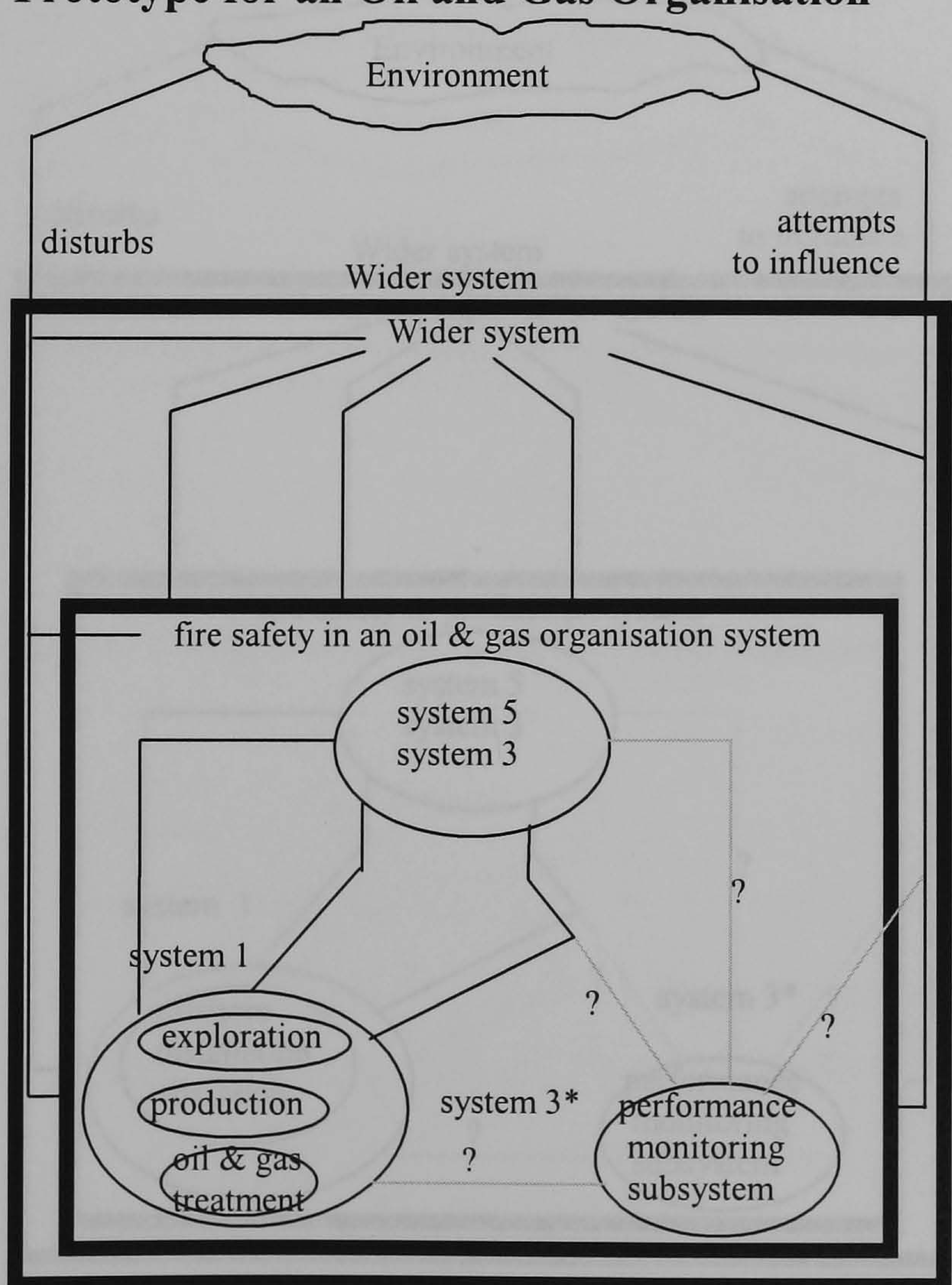
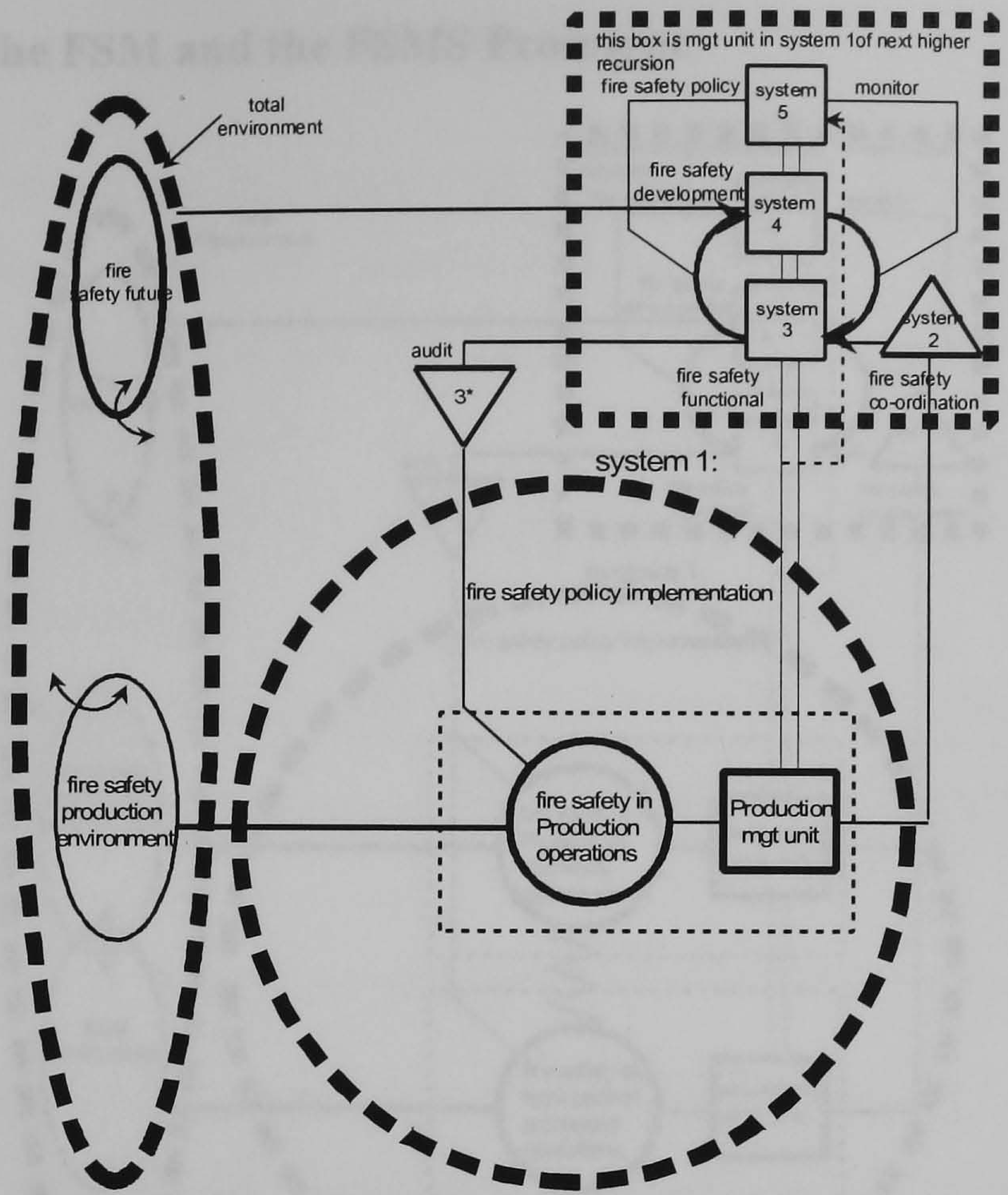
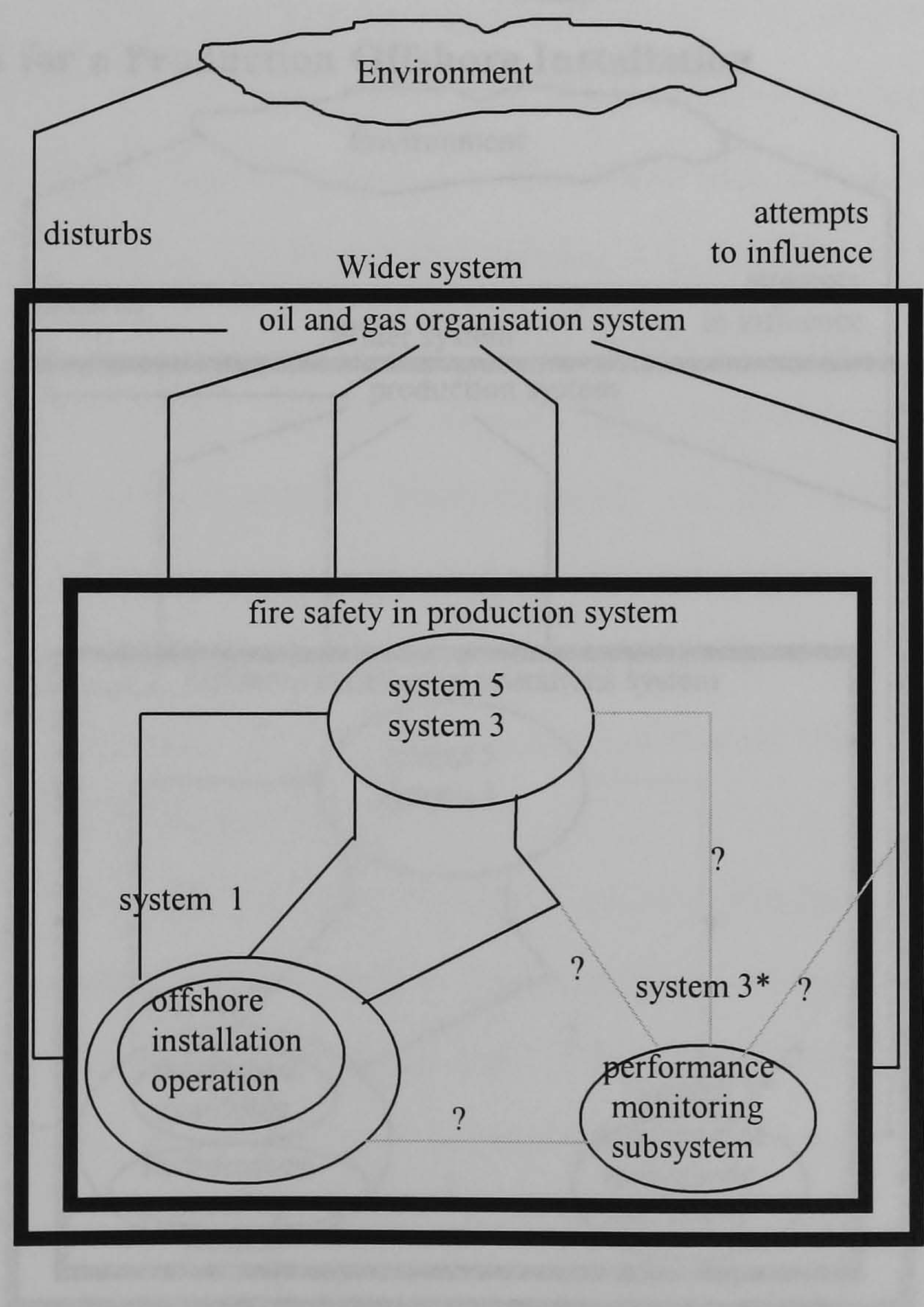


Figure 4.7 The FSM and the FSMS Prototype

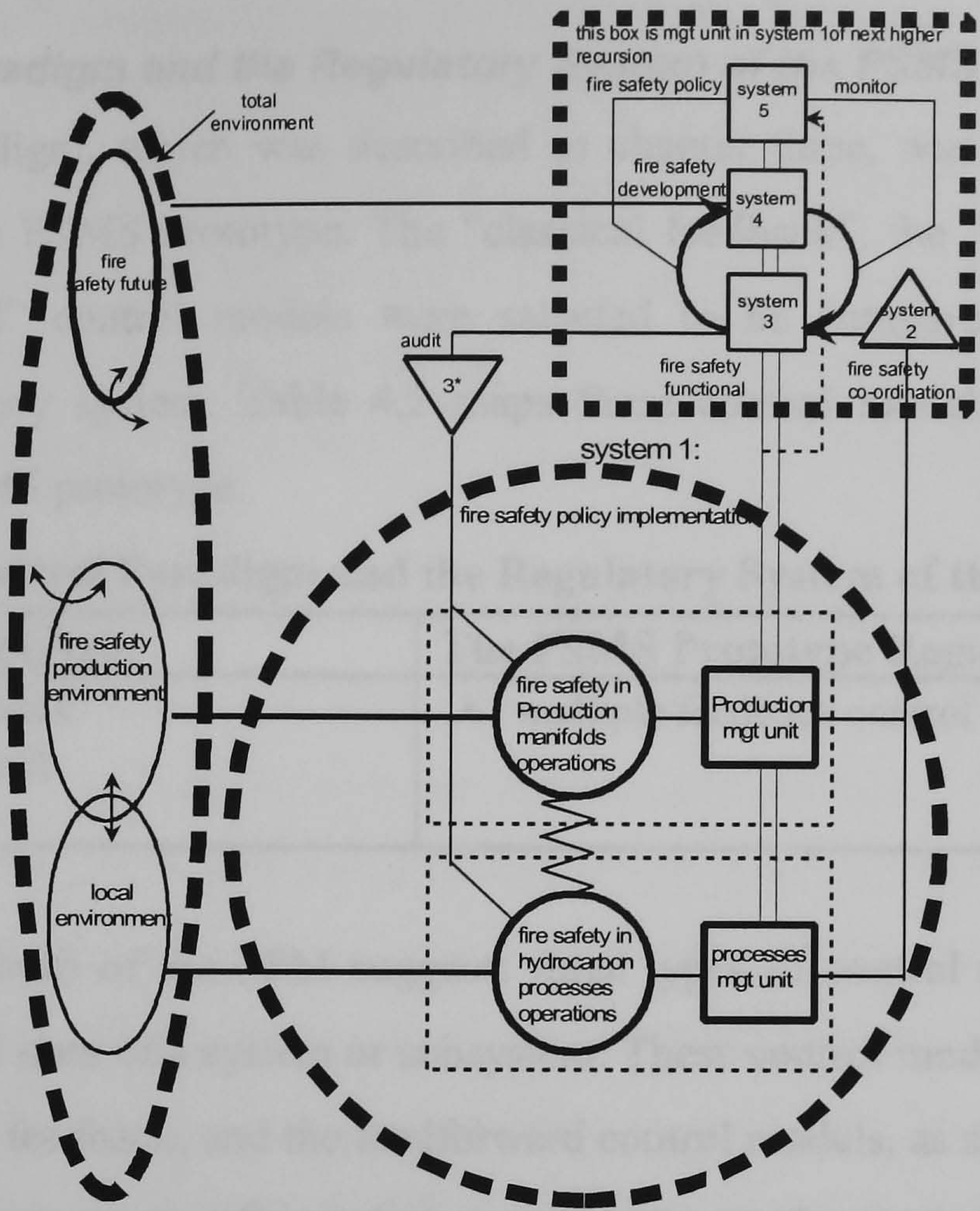


(b) An FSMS Prototype for an Oil and Gas Production Operations

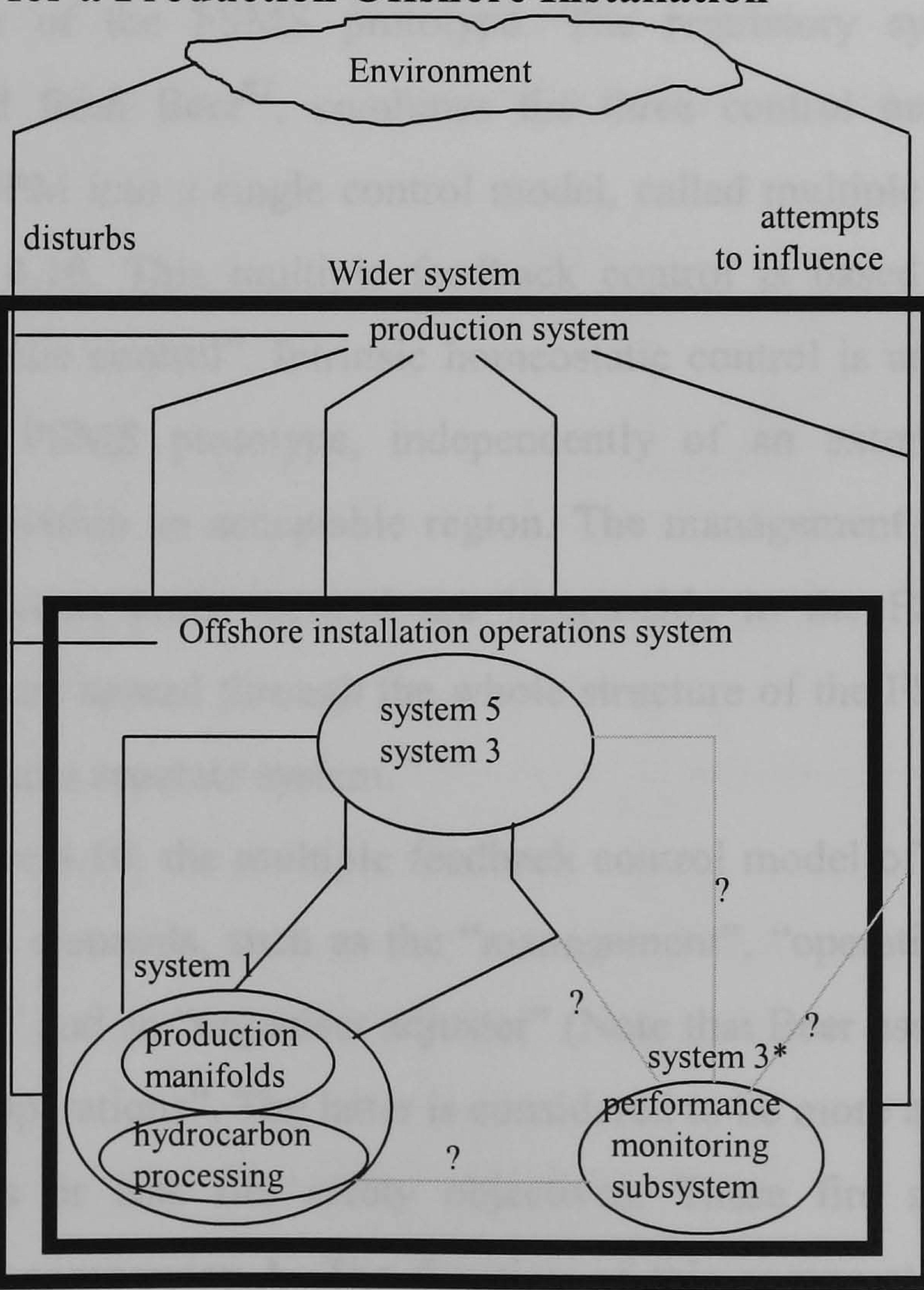


(b) The FSMS Prototype in the format of the FSM

Figure 4.10 The FSM and the FSMS Prototype



(a) An FSMS for a Production Offshore Installation



(b) The FSMS Prototype in the Format of the FSM

Figure 4.9 The FSM and the FSMS Prototype

The Control Paradigm and the Regulatory System of the FSMS Prototype

The control paradigm, which was described in chapter three, was compared with its counterpart in the FSMS prototype. The "classical feedback", the "modern feedback", and "feedforward" control models were selected to be compared with the FSMS prototype regulatory system. Table 4.2 maps these control models to the regulatory system of the FSMS prototype.

Table 4.2 The Control Paradigm and the Regulatory System of the FSMS

The Control Paradigm	The FSMS Prototype Regulatory System
• classical feedback • modern feedback • feedforward	• multiple feedback control

The control paradigm of the FPM suggests three types of control models in order to maintain a desired state of a system or subsystem. These control models are the classical feedback, modern feedback, and the feedforward control models, as shown in Table 4.2. It seems that there is no significant discrepancy between the control paradigm and the regulatory system of the FSMS prototype. The regulatory system of the FSMS prototype, derived from Beer[82], combines the three control models of the control paradigm of the FPM into a single control model, called multiple feedback control, as shown in Figure 4.10. This multiple feedback control is based on the principle of "intrinsic homeostatic control". Intrinsic homeostatic control is understood here as the capability of the FSMS prototype, independently of an external management, to maintain fire risk within an acceptable region. The management or controller and the system or organisation under control are inseparable in the FSMS prototype. The sources of control are spread through the whole structure of the FSMS prototype rather than localised within a separate system.

As shown in Figure 4.10, the multiple feedback control model of the FSMS prototype consists of various elements, such as the "management", "operations", "comparators", "feedback adjuster" and an "organiser adjuster" (Note that Beer uses the phrase "Muddy Box" instead of "Operations". The latter is considered to be more appropriate here). The management plans or sets fire safety objectives. These fire safety objectives are represented in the comparator **A**. The function of this comparator is to compare the 'actual output' with the planned fire safety objectives. Thus this control model can detect any deviation of the planned fire safety objectives through the comparator **A**. The "feedback adjuster" involves adjusting the input of the "operations" for the time lags. Otherwise, the purpose of the FSMS will not be accomplished so the entire organisation will be unstable. It is understood here as being a stable FSMS when its "feedback adjuster" can predict and classify factors that can go wrong, examine the consequences and likelihood of those failures, and attempt to stop those most likely to occur. It should also be able to predict and categorise threats and opportunities from the FSMS environment.

The adjuster organiser, on the other hand, is intended to manage fire safety in the face of potential unclassified factors, as well as uncategorised threats and opportunities. In other words, the adjuster organiser involves anticipating any deviation of the organisation's fire safety objectives due to unforeseen factors as well as predictable factors. In order to do so, the adjuster organiser involves modifying the design of the feedback adjuster and checking the process whereby the feedback adjuster copes with the time lags through the comparator **B**. This process can be accomplished through modelling fire safety for the whole system which the feedback adjuster is trying to deal with. If the FSMS is able to do so, then it can be said that the FSMS is an adaptive system. Thus, an adaptive FSMS should be capable of maintaining an acceptable level of fire risk in the face of unforeseen factors.

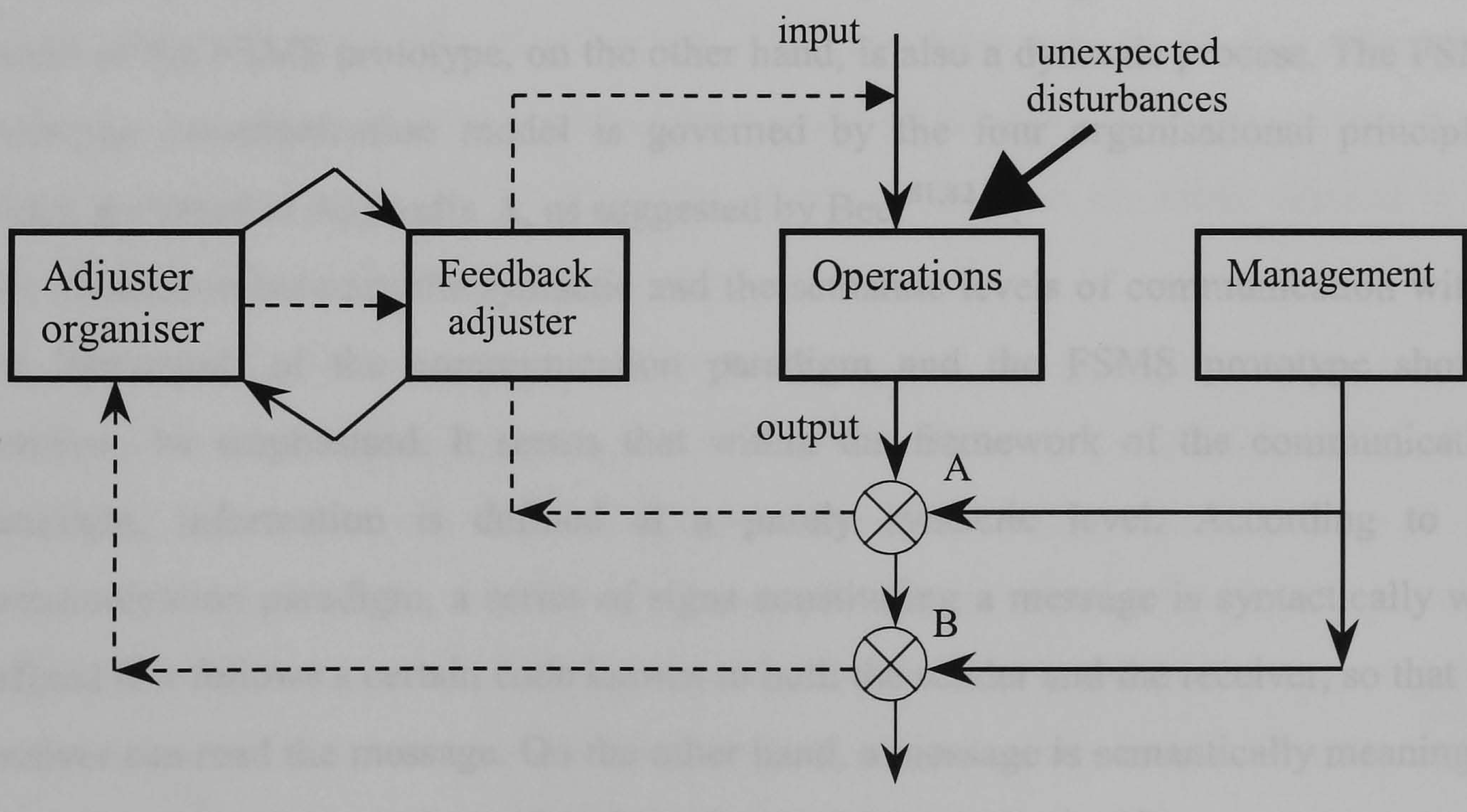


Figure 4.10 Multiple Feedback Control (from Beer)[82]

That is , the feedback adjuster is essentially 'reactive', whereas the adjuster organiser is 'pro-active'. A simple example on how to control a system through this multiple feedback control model could be a truck carrying hazardous materials. The truck and its route represent the "operation", and the dispatcher as the "management". The dispatcher schedules the journey of the truck and this schedule is being represented in A, as shown in Figure 4.10. The dispatcher monitors the schedule of the truck and detects any deviation of the actual truck schedule from the planned schedule. If a deviation is detected, the dispatcher may elaborate a new plan, feedback adjuster, in order to achieve the planned schedule of the truck. Considering that the truck is scheduled to drive through a region where a snow storm is expected or already in progress; the dispatcher could "anticipate" by assessing the impact of such an event on the planned route and evaluate alternative routes. This process of changing plans is the function of the adjuster organiser.

The Communication Paradigm and the FSMS Prototype

In comparing the communication paradigm with the communication model of the FSMS prototype, there appear to be no discrepancies. In essence, both the communication paradigm suggested by Fortune and Peters[85] and the communication model of the FSMS are based on the same communication theorem developed and proposed by Shannon[82,83,85]. Fortune and Peters' communication model is a dynamic model in which the sender and the receiver can adapt to changes. Also, the receiver's response to the sender's message can be used to modify subsequent messages. The communication model of the FSMS prototype, on the other hand, is also a dynamic process. The FSMS prototype communication model is governed by the four organisational principles, which are listed in Appendix **A**, as suggested by Beer[81,82,83].

The distinction between the syntactic and the semantic levels of communication within the framework of the communication paradigm and the FSMS prototype should, however, be emphasised. It seems that within the framework of the communication paradigm, information is defined at a purely syntactic level. According to the communication paradigm, a series of signs constituting a message is syntactically well defined if it follows a certain code known to both the sender and the receiver, so that the receiver can read the message. On the other hand, a message is semantically meaningful if the receiver cannot only read it, but also understand its significance. A message is meaningful to the receiver only if it has practical meaning to him or her. The information content of the message is competent to effect change to the receiver's purposeful orientation. Information is understood as the set of facts that changes systems. The syntactic aspect of the communication paradigm can be handled by information processing systems. The semantic aspects of information, on the other hand, can be handled only by humans.

It should also be emphasised that the syntactic and the semantic aspects of communication are dealt with in the FSMS prototype, though they are not explained explicitly. There is therefore a need to make them explicit in the FSMS model. In the communication model of the FSMS prototype, fire safety information is a set of facts that is competent to effect change in both technical and human factors. The channels of communication of the FSMS prototype rely on the four organisational principles as discussed in Appendix A. A special attention is given to the "Tenth Theorem" of Shannon as discussed elsewhere[81,82]. This theorem emphasises that the channel capacity must exceed its notional adequate bit-handling ability, to resolve ambiguities that may arise in passing the message because of 'noise' in the system. Noise is understood as mistaken information or data "in disguise" This has become the second principle of organisation of Beer (see appendix A). Data may be understood as a statement of fact. The channels of communication of the FSMS prototype are concerned with both the syntactic and the semantic aspects of information. According to the four organisational principles, the channels are concerned with flow of bits (in the computer sense) and the flow of variety, both of which are syntactic information flows. Variety is defined as the number of possible states of a system. The semantic aspects of the information transmitted by the channels are the entire variety of the fire safety information in the form of plans and reports. These aspects of communication are made explicit in the FSMS model, as described in chapter five.

The 'Human Factors Paradigm' and Human Aspects of the FSMS Prototype

Table 4.3 maps the 'human factors paradigm' of the FPM to the human aspects of the FSMS prototype. There is no single human factors paradigm as such. Fortune and Peters, for example, refer to many principles, studies, etc. which would be expected to be of value. With this caveat in mind one might think of a 'human factors paradigm' as generally stressing that having the technology in place is no guarantee of safety unless the human discipline required to follow prescribed procedures and good operating practices is understood.

Table 4.3 The 'Human Factors Paradigm' and the FSMS Prototype

'Human Factors Paradigm'	Human Aspects of the FSMS Prototype
Organisational level • safety culture paradigm	• not explicit
Group level • anomic reactive paradigm • team cult paradigm • team primacy paradigm	• not explicit
individual level	• not explicit

As can be seen in Table 4.3, human factors are not dealt with explicitly in the FSMS prototype. The human aspects, such as decisions and activities, must be central in the FSMS prototype if the system is to be capable of operating effectively. Clearly, the developed FSMS prototype does not take into account explicitly human aspects, such as the values and beliefs and circumstances of the people who make decisions, communicate and accomplish activities. Human aspects in teams, groups, individual, inter-departmental links and intra-departmental links should be integrated into the final FSMS model.

4.4.3 Improvements in the FSMS prototype

The FSMS prototype described in section 4.3 is a conceptual model that is intended to maintain an acceptable fire risk in an oil and gas organisation's operations. A typical oil and gas offshore production platform has been used to construct the FSMS. The systemic approach taken to formulate the FSMS builds on the VSM proposed by Beer[81,82,83]; the VSM has been described in some detail in chapter three. Vulnerabilities and strengths of the FSMS prototype have been investigated in order to develop further the FSMS. The Formal System Model (FSM), which has been described in chapter three, was mapped to the FSMS prototype. Major discrepancies between the FSM paradigms and the FSMS prototype were discussed in section 4.4.2. From these discrepancies, some feasible and desirable changes to the FSMS prototype are listed in Table 4.4 in order to construct a FSMS model.

According to Table 4.4, the FSM suggests that the FSMS prototype requires a "performance monitoring subsystem". However, the structural organisation of the FSMS prototype does not require a specific subsystem for monitoring its fire safety performance. The main reason is that, as discussed above, the fire safety performance monitoring is spread throughout the structural organisation of the FSMS prototype rather than localised into a specific subsystem.

Table 4.4 Summary of Improvements in the FSMS Prototype

Failure Paradigm Method	FSMS Prototype
• formal system model (FSM)	• performance monitoring subsystem not necessary • consider next higher level of recursion
• control paradigm	• incorporate a fire safety measurement system
• communication paradigm	• no significant changes
• "human factors paradigm"	• make explicit the involvement and participation of individuals within teams, groups, departments, inter-departments that form an organisation • incorporate a fire safety reporting system into the FSMS structural organisation

As described in section 4.3.2, a typical offshore production platform, as shown in Figure 4.5, was used to construct the FSMS prototype. It seems that a desirable change to the structural organisation of the FSMS prototype could be to consider higher levels of recursion. This is, extend the structural organisation of the FSMS prototype to address other platforms as well and, indeed, the whole oil and gas organisation, which operates not only offshore production facilities but also exploration, oil and gas treatment operations.

It seems that there are no major discrepancies between the "control paradigm" and the regulatory system of the FSMS prototype, as illustrated in Table 4.2. However, the FSM requires the FSMS prototype to have a separate subsystem to monitor its fire safety performance. This is not a feasible change for the reasons exposed in the preceding paragraph. A system that can help to quantify the FSMS fire safety performance needs to be developed instead. This involves suggesting a system that may help to define fire safety levels, to develop fire safety plans and to measure the fire safety performance of the FSMS.

As can be seen in Table 4.4, the communication model of the FSMS prototype does not require significant changes. Both the communication paradigm and the communication model of the FSMS prototype are based on the same principles. Table 4.3 shows the discrepancies between the 'human factors paradigm' and the human aspects of the FSMS prototype. The 'human factors paradigm' of the FPM has shed light on important aspects of human behaviour, either individually, within teams or groups, or within an organisation as a whole, to prevent possible failures. However, it must be emphasised that safety culture and human factors regarding safety have been a subject of a large amount of research and publication in the literature. Detailed aspects of safety and fire safety culture, and human factors are not dealt with here.

An important lesson that has been drawn from the 'human factors paradigm' of the FPM, is that people who manage and operate a system or organisation need to have an understanding about the interaction of the human, technological, structural organisation, and environmental factors that determine the safety of the system or organisation as a whole. According to these, two major changes need to be made in the FSMS prototype regarding human aspects. First, there is a need to replace the emphasis on purely technical explanations of goal-directed systems. This means that the FSMS should not only enable the effectiveness and efficiency of people or machines to accomplish an external motive or objective, but enable the involvement and commitment of humans regarding their fire safety purposes. This has led on to the concepts of the Internally Committed systems (ICS) and Externally Committed Systems (ECS); described in greater detail in chapter 5, section 5.3.2. Second, another important lesson that has been learnt from the 'human factors paradigm' is that an organisation needs to take a positive attitude and encourage people to report their errors, near misses, or provide essential safety related information. A special subsystem that deals with special reports should be incorporated into the structural organisation of the FSMS. This subsystem needs to ensure confidentiality for the person doing the reporting (see chapter 5, section 5.3.3).

A Fire Safety Management System (FSMS) model has been the result of all these changes. This model is presented in the synthesis stage of the inquiry process, as shown in Figure 4.8 and it is described in chapter five.

4.5 Conclusion

This chapter has discussed fire safety in the context of oil and gas offshore platforms. It described the developed FSMS prototype for a typical oil and gas production platform. The chapter proceeded by describing a process used to identify strengths and vulnerabilities of the FSMS prototype. It continued by discussing the main discrepancies between the FSMS prototype and its counterpart of the FPM. Finally, the chapter discusses some major improvements that required to be accomplished in order to construct a FSMS model, which is the subject of chapter five.

Chapter Five

Synthesis: A Fire Safety Management System Model

5.1 Introduction

Chapter one emphasised the need for a systemic approach to fire safety that may help organisations to manage fire safety more effectively. Chapters two and three have established the theoretical basis for constructing a robust FSMS model. Chapter four presented a prototypical FSMS, which was further developed as described in section 4.4 of chapter four. The developed FSMS model is an intended to maintain fire risk within an acceptable region in an organisation's operations. This chapter presents an exposition of the FSMS model. Section 5.2 provides an overview of the FSMS model. A detailed description of the FSMS model is given in section 5.3. Section 5.4 describes a framework called 'fire safety configuration space', which is intended to help to characterise acceptable and unacceptable fire safety regions in which organisations can "navigate". Finally, section 5.5 summarises chapter five.

5.2 Overview of the FSMS Model

The approach taken to formulate the FSMS builds on the Viable System Model (VSM) and the Failure Paradigm Method (FPM), which were described in chapter 3, sections 3.2 and 3.3 respectively. The VSM facilitated an understanding to help formulate the structural organisation of the FSMS. The FPM, *inter alia*, provided some paradigms that helped to understand some human aspects.

In essence, the FSMS is a systemic set of five inter-related subsystems, as shown in Figure 5.1. The FSMS needs to achieve five functions associated with systems 1 to 5. System 1, *fire safety policy implementation*, implements the organisation's fire safety policy. System 2, *fire safety co-ordination*, involves co-ordinating the various operations of system 1. System 3, *fire safety functional*, involves ensuring that the organisation's fire safety policy is implemented, as well as ensuring that the fire risk is maintained within an acceptable region. System 3*, *fire safety audit*, conducts sporadic audits into the operations of system 1. System 4, *fire safety development*, is responsible for the future fire safety development for the whole organisation. System 4*, *fire safety confidential reporting,* deals with the confidential fire safety concerns of the organisation's employees. Finally, system 5, *fire safety policy*, is responsible for establishing fire safety policies for the whole organisation.

The FSMS model developed and presented in this research project not only addresses both technical and human factors, but also immediate and latent factors. It proposes a system that is intended to measure an organisation's fire safety performance. These measures of fire safety performance provide decision makers with the means to define fire safety levels, plan fire safety, and measure fire safety performance. Moreover, a fire safety configuration space has been devised to help to characterise acceptable and unacceptable regions of fire safety in which organisations can "navigate" (see section 5.4). A detailed description of the FSMS is given in the next section.

5.3 Description of the FSMS Model

This section presents detailed aspects of the developed FSMS model. It begins by discussing the structural organisation of the FSMS model. It continues by describing the channels of communication and control of the FSMS model. The case of an oil and gas organisation has been used to describe the FSMS, though the model is general.

5.3.1 Recursive FSMS Structural Organisation

The FSMS needs to achieve five functions associated with systems 1 to 5. System 1 consists of various operations within an organisation that deal directly with the organisation's production activities.

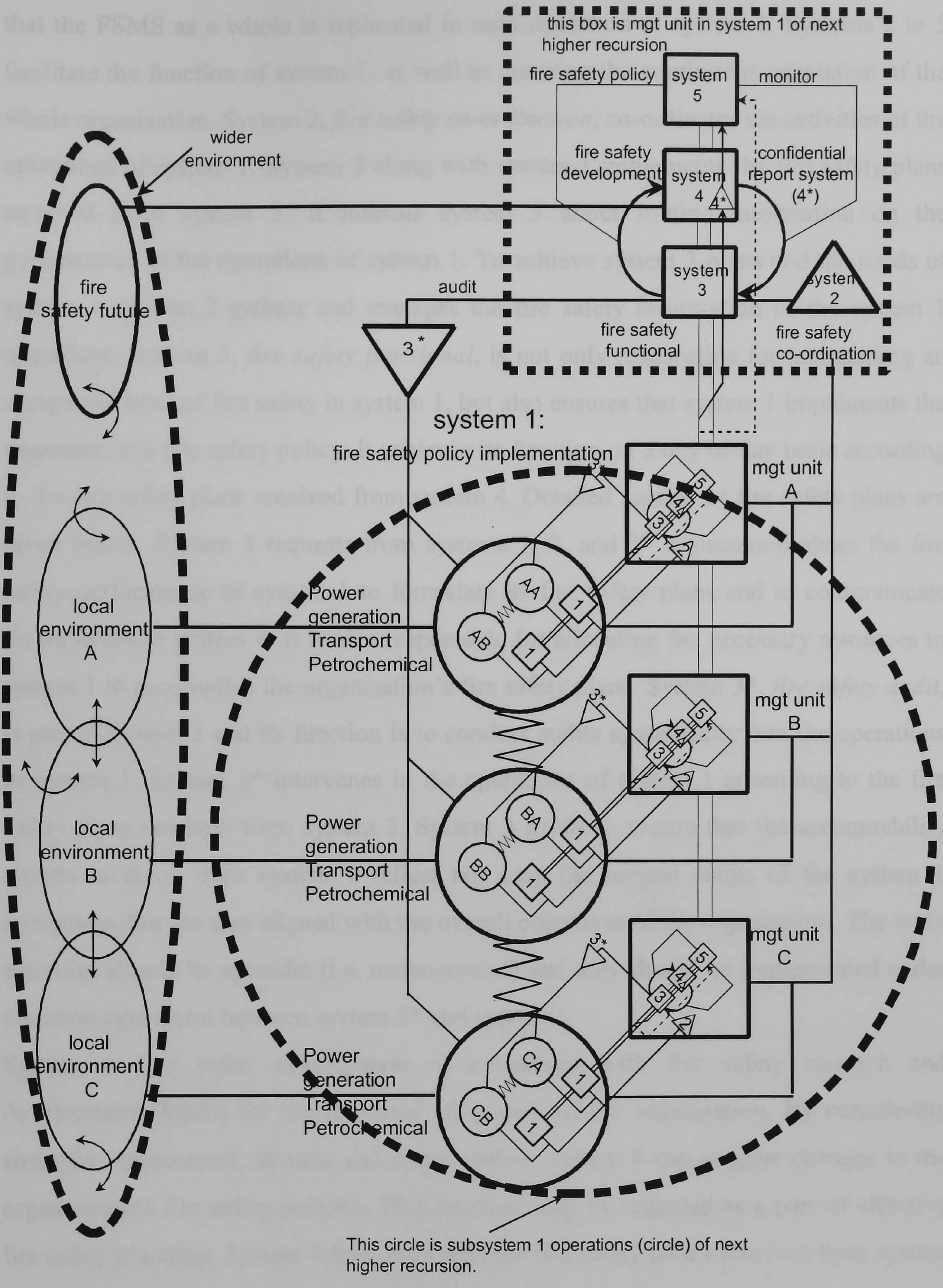


Figure 5.1 A Fire Safety Management System Model

A typical organisation's operations, for example, power generation, transport, oil and gas exploration, production, and treatment could form part of system 1, as shown in Figure 5.1. It should be noted that each operation performs five functions namely fire safety policy, development, functional, co-ordination, and implementation. This means that the FSMS as a whole is replicated in each operation of system 1. Systems 2 to 5 facilitate the function of system 1, as well as ensuring the continuous adaptation of the whole organisation. System 2, *fire safety co-ordination*, co-ordinates the activities of the operations of system 1. System 2 along with system 1 implements the fire safety plans received from system 3. It informs system 3 about routine information on the performance of the operations of system 1. To achieve system 3 plans and the needs of system 1, system 2 gathers and manages the fire safety information of the system 1 operations. System 3, *fire safety functional*, is not only responsible for maintaining an acceptable level of fire safety in system 1, but also ensures that system 1 implements the organisation's fire safety policy. It achieves its function on a day-to-day basis according to the fire safety plans received from system 4. Detailed aspects of fire safety plans are given below. System 3 requests from systems 1, 2, and 3* information about the fire safety performance of system 1 to formulate its fire safety plans and to communicate future needs to system 4. It is also responsible for allocating the necessary resources to system 1 to accomplish the organisation's fire safety plans. System 3*, *fire safety audit*, is part of system 3 and its function is to conduct audits sporadically into the operations of system 1. System 3* intervenes in the operations of system 1 according to the fire safety plans received from system 3. System 3 needs to ensure that the accountability reports received from system 1 reflect not only the current status of the system 1 operations, but are also aligned with the overall objectives of the organisation. The audit activities should be sporadic (i.e. unannounced) and they should be implemented under common agreement between system 3* and system 1.

System 4, *fire safety development*, is concerned with fire safety research and development (R&D) for the continual adaptation of the organisation. By considering strengths, weaknesses, threats, and opportunities, system 4 can suggest changes to the organisation's fire safety policies. This function may be regarded as a part of effective fire safety planning. System 4 first deals with the fire safety policy received from system 5. Second, it senses all relevant threats and opportunities from the wider physical and socio-economic infrastructure of the organisation, including the fire safety future environment. Third, system 4 deals with all relevant needs of system 1 performance, and its potential future. Finally, it deals with the confidential or special information communicated by system 4*. System 4*, *fire safety confidential reporting,* is part of system 4 and it is concerned with confidential reports or causes of concern that may require the direct and immediate intervention of system 5. Finally, system 5, *fire safety policy*, is responsible for deliberating fire safety policies and to making normative decisions. According to alternative fire safety plans received from system 4, system 5 considers and chooses feasible alternatives, which aim to maintain an acceptable level of fire safety throughout the organisation's operations. It also monitors the interaction of system 3 and system 4, as represented by the lines that connect the loop between systems 3 and 4 as shown in Figure 5.1.

The FSMS and Its Environment

The FSMS relies on five functional imperatives and the extent to which the FSMS structural organisation accommodates contextual constraints determines its ability to adapt. The organisational structure of the FSMS is shown as interacting in a defined way with its environment through system 1 operations, and through system 4, as illustrated in Figure 5.1. Environment, both socio-economic and physical is understood as being those circumstances to which the FSMS response is necessary. The FSMS also needs to respond to necessary internal matters, e.g., inadequate training. System 4 deals with the FSMS's total or wider socio-economic and physical environment into which an organisation is embedded. The broken line elliptic symbol represents the FSMS total environment, as illustrated in Figure 5.1. System 4 deals also with the fire safety 'future environment', which is also embedded into the FSMS total environment. The fire safety future environment is concerned with threats and opportunities for the future development of fire safety. On the other hand, system 1 operations deal with local environments or institutionalised environments with which the organisation's operations must deal. These local environments are embedded into the total environment of the FSMS as illustrated in Figure 5.1. For example, organisations are embedded within a wider socio-economic and physical structure that will constrain the way they can develop. There are various important socio-economic and physical characteristics that need to be taken into account. These characteristics can be segregated thus; first physical characteristics, such as the geography of the area, for example the North Sea oil and gas fields, weather conditions and public utilities. Second, economic characteristics such as oil and gas markets, level of employment, other oil and gas operators and other types of industry and commerce, and finally, socio-political characteristics, such as regulators, and social organisations. The demands and needs inherent in these characteristics will suggest and condition patterns of structural organisation of the FSMS. Organisations need to pay more attention not only to these characteristics, but also to the complexity, stability or uncertainty of changing technologies.

Apart from confronting demands for its products, an organisation faces an environment upon which it is dependent for finance, work-force and materials, that is, for its resources. The organisation's total environment has a certain pattern of resource availability to which the organisation has to relate. The supply of resources to the organisation changes over time forcing it to make organisational adaptations. These adaptations may involve merging departments, changing the location of decision making, introducing new procedures, and so on. These changes may have significant impacts on the fire safety performance of the whole organisation. Similarly, local or institutionalised environments also are characterised by the socio-economic and physical characteristics of the organisation's total environment. These characteristics can be segregated into a) physical characteristics, for example a specific oil and gas production field, local weather conditions; b) economic characteristics, for example other oil and gas field operations, and c) socio-political characteristics, such as government regulations, for example, the safety case regulations.

Whenever a line appears in the figure representing the FSMS model, it represents a channel of communication, except for the lines that connect the balancing loop that connects systems 4 and 3. The zigzag lines connecting the operations of system 1 indicate an inter-dependency, which may be strong or weak according to the degree of interdependence amongst the operations. There is a particular concern in the FSMS about the nature of these channels and the information which flows in the communication channels. These channels of communication obey four organisational principles. These organisational principles are understood as responding appropriately to the weaknesses and strengths, and threats and opportunities as presented in the wider and local environment of the FSMS; the channels of communication, and the necessary transducers translating information when it crosses boundaries of systems must be designed according to the requirements of Ashby's law of requisite variety[82,83,84,152]; and these principles must be put into effect without time-lags. The bi-directional arrows represented in the FSMS total environment indicate the interactions among the local environments, as well as the interaction of these local environments with the total environment.

Recursive Structure and Autonomy

According to Beer[82], in a recursive organisational structure any viable system contains, and is contained in a viable system. This means that the organisational structure of the FSMS for the organisation as a whole is replicated in each operation of system 1. That means that the FSMS model is intended to manage fire safety of an organisation in three levels of recursion, as shown in Figure 5.1 (The three levels should be seen in the context of Figure 4.2). The top right hand side broken line square box is the management unit of system 1 of the next higher level of recursion. The operations of system 1, on the other hand represent the FSMS for the level of recursion next below, depicted at 45 degrees in Figure 5.1. The FSMS for the organisation as a whole is replicated for every operation of system 1.

Very little attention has been given by both academe and practitioners to understanding the appropriate degree of interdependence amongst the parts that constitute an organisation in order to design an effective SMS. In addition, the impact of the organisational structure on the effectiveness of the SMS, as well as on the subsystems of the SMS, is not well understood. The FSMS is organised in recursive levels, which may have a significant impact not only in designing a more effective FSMS, but also a SMS, including health, safety and environment. The FSMS for the whole organisation is replicated in each operation of system 1, as illustrated in Figure 5.1. The FSMS is intended to be able to maintain an acceptable level of fire safety at each level of recursion, but this fire safety achievement, at each level, is conditional on the cohesiveness of the whole organisation. The FSMS contains a structure that favours *autonomy* and the local fire safety problem-solving capacity. Autonomy means that each operation of system 1 of the FSMS is responsible for its own activity with minimal intervention of systems 2, 3, 4, and 5. The organisational structure of the FSMS allows decisions to be made at the local level. Decision making is distributed throughout the whole organisation. This means that distributed decision making involves a set of decision makers in each operation of system 1 and at each level of recursion. These decision makers should be autonomous in their own right and act independently based on their own understanding of fire safety and their specific tasks. However, it should be recognised that they have interdependence with other decision makers of other operations of system 1. Therefore, each operation of system 1 should be endowed with autonomy so that the organisational fire safety policy can be achieved more effectively.

These aspects of organisational structure, which have a role in making organisations more rather than less effective, are poorly understood in safety and fire safety literature.

5.3.2 Communication and Control in the FSMS Model

Pro-active Commitment to Fire Safety

An organisation's safety approach can be reactive or pro-active and less or more committed to safety. Additionally, organisations may focus on technical aspects of incidents or accidents. For example, passive and active fire fighting systems have been developed with the purpose of controlling and mitigating fire incidents or accidents. However, the degree of safety in an organisation or system is an emergent property resulting from the interrelated activities of people who design it, manage it, and operate it. Humans, individually, in teams and in organisations decide the technical aspects. People who are involved in the product, service, or process life cycle, such as product and plant designers, constructors or manufacturers, operators or users and maintainers make decisions which effectively determine the risk. Furthermore, there is the need to look at the people responsible for designing and managing the organisation or system itself. These factors, which are the potential, but not obvious or explicit causes of fire incidents or accidents, are known here as *latent factors*. It is claimed elsewhere[152] that these common causal failures form part of an "incubation process" in a sequence of disaster development. Moreover, latent factors accumulate unnoticed until a precipitation event or trigger leads to the onset of the incident, accident or disaster[7,11,16,17,18,19].

Traditionally, organisations may not be aware of latent factors, but they look for immediate causes of fire incidents or accidents after they have taken place. Both academe and practitioners tend to divide them into separate objects and events. This division is, of course, useful and necessary to cope with risk, but is not a fundamental feature of a real fire safety situation. Immediate causes of fire incidents or accidents as readily observed or understood are known here as *immediate factors*. The "incubation" period of a "latent failure" before the immediate failure appears is known as the "latent period". It is contended here that all parts that constitute an organisation can be seen as interdependent and inseparable parts of the organisation as a whole. Moreover, these constituents are all interconnected, interrelated and interdependent in that they cannot be understood as isolated entities, but only as integrated parts of the organisation as a whole. Fire loss is therefore seen as a systemic failure, not a result of a single cause. Clearly, addressing latent failures is as important as focusing on apparent failures of fire incidents or accidents.

In addition to latent and immediate factors, the distinction between technical and human factors should be emphasised so that realistic fire safety objectives, plans and measures of performance can be set. This distinction should replace the emphasis on unique causes and isolated technical explanations of failure of systems. This will require knowledge about the degree to which the technical and human factors are committed to fire safety and linked together into a coherent whole. Moreover, the way in which they are implemented into a particular organisation's operations should be clearly understood. These two aspects are known here as Internally Committed Systems (ICS) and Externally Committed Systems (ECS). The distinction between these two aspects may be a source of insight into the ways fire safety can be approached, as well as the ways in which these two aspects differ from each other. Table 5.1 illustrates some characteristics of ICS and ECS.

Table 5.1 Internally and Externally Committed Systems

External Commitment	Internal commitment
Tasks in the organisation are defined by others	Employees participate in defining tasks
The behaviour required to perform tasks with an acceptable degree of risk is defined by others	Employees participate in defining the behaviour required to perform tasks with an acceptable degree of risk
Fire safety performance goals are defined by the organisation management or others	Organisation's management and employees jointly define fire safety performance goals
Others define the importance of the fire safety performance goals.	Employees participate in defining the importance of the goals

ECS refers to the fire safety performance of systems that are committed to a particular purpose, function, or objective based on external reasons or motivation. This definition addresses both technical aspects and humans. For example, production installations are designed to accomplish a well-defined objective, whilst the production operations' procedures are formulated by process designers to be followed by production personnel. Here, the performance of production machines satisfy the purpose of product designers and the production personnel satisfy production process designer's purpose. Traditionally, organisations tend to address fire safety by seeking the direct or immediate causes of fire incidents or accidents after they have taken place. An inquiry or assessment process is conducted to determine the immediate causes so that the existing understanding is adjusted to fit the newly gained understanding of fire safety. Goals for improvement are defined to address the newly found failure so that the same failure will not occur again. Moreover, very often it is assumed by organisations that the absence of incidents or accidents or other negative outcomes is an indication of good safety management. For example, some oil and gas organisations, like many others, use traditionally lost time injuries (LTI) and deaths as the basis to measure the effectiveness of their safety management.

More recently, organisations have tended to address fire safety pro-actively, but they still tend to comply with external fire safety objectives, that is, existing regulations, standards or procedures. It is generally accepted that safety is better assessed and managed by addressing in advance the hazards of the organisation's operations. This is usually done through i) a systematic identification of hazards, ii) assessment of the significance of hazards, and iii) hazard management by prevention, control, and mitigation. However, organisations are often still only committed to complying with existing regulations, standards or procedures and this is basically reactive mentality. Only complying with externally imposed regulations or existing standards does not necessarily mean that an organisation's operations are 'acceptably safe'. Moreover, organisations still tend to focus on immediate factors and have very little understanding of latent factors and ICS.

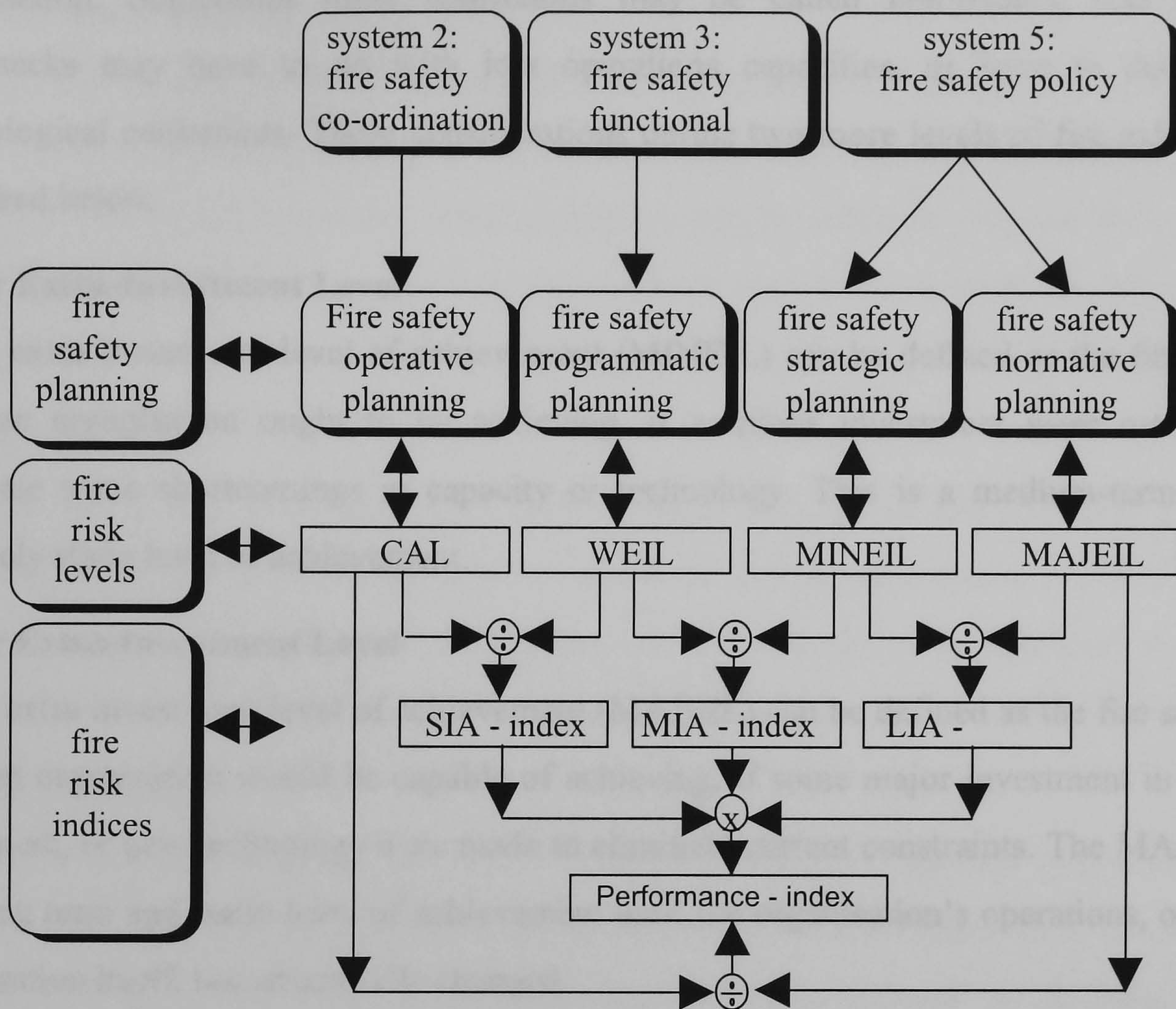
The idea of ECS may produce important insights into the ways fire safety can be addressed, but it is fundamentally incomplete. There is growing evidence that human factors have quite dramatic safety and fire safety consequences; this requires a fundamentally different approach. It seems that there is a substantial gap between fire safety objectives as defined by regulators, standards or procedures, or the organisation's management and what may be achieved in a real fire safety situation. It is necessary to introduce the idea of ICS. An ICS is a system that is committed to a particular purpose or objective based on its own reasons or motivation. In other words, an ICS refers to the critical awareness of self-reflective human beings regarding their purposes and the implications of their actions for all those who might be affected by the consequences. This means that all those involved in the life cycle of the organisation's operations should be committed to address fire safety pro-actively and anticipate fire incidents or accidents, motivated by their own objectives or purposes. This freedom to achieve fire safety objectives is, however, limited by the organisation's fire safety policy, plans, standards and procedures. Individuals, teams, groups, and departments that perform an organisation's operations should not only be assigned tasks but they should have both authority and responsibility by their understanding of fire safety and their specific tasks. They should be endowed with authority in their daily tasks by their knowledge to perform their tasks properly and in an acceptable way with regard to risk. This knowledge involves their knowledge of fire safety itself and the skills required to perform a specific activity. In other words, individuals, teams, groups and departments that constitute an organisation should have more involvement with fire safety in their daily tasks. Top and line management should encourage the development of ICS. The more the organisation's management wants internal commitment from its employees, teams, and departments the more it must try to involve employees in defining fire safety objectives, specifying what these are and how to achieve them, and setting fire safety targets. There is no fire safety vision, strategy or policy that can be achieved without able and committed employees. However, it is unrealistic to expect the management of an organisation to allow total autonomy to employees. The degree to which internal commitment is plausible is certainly limited.

Measuring Fire Safety Performance

This section presents a systemic model that intends to provide a means to quantify an organisation's fire safety performance. This system is built on the measures of performance proposed by Beer[81,82,106]. It provides decision makers with a means to define fire safety levels, fire safety plans, and measure fire safety performance. This system consists of four levels of fire safety, four kinds of fire safety plans, and four kinds of fire safety indices, as illustrated in Figure 5.2. These measures of fire safety performance may be used as a comprehensive system to measure an organisation's fire safety performance for all types of resources throughout the organisation. Moreover, the measures of fire safety performance presented here not only contain both ECS and ICS, but also incorporate latent and immediate factors, as described below.

Levels of Fire Safety Achievement

Four different levels of fire risk can be specified to plan and measure an organisation's fire safety performance, as shown in Figure 5.2. The first, current, fire risk level is a continuous fluctuating value. The second, without extra investment, fire risk level is a relatively static value. On the other hand, the minor extra investment and the major extra investment fire risk levels are static values until the organisation's operations, or the organisation itself has structurally changed. It should be stressed that when defining these fire risk levels, it is necessary to consider both ICS and ECS for immediate factors and latent factors. It should also be emphasised that immediate factors are directly related with fire risk, whilst latent factors do not directly relate to risk. A detailed description of these fire risk levels is given below.



5.2 Measures of Fire Safety Performance

Current Achievement Level

Current achievement level (CAL) is the fire risk level an organisation is managing now with existing resources and under existing constraints. CAL expresses the day-to-day fire risk level in the organisation's operations. It expresses a continuous fluctuating value of risk levels. The continuous variation of fire risk level requires organisations to have up-to-date fire safety information. If fire safety information is out of date, then the decision of the organisations may be irrelevant. Moreover, organisations need to manage fire safety continuously.

Without Significant Extra Investment Level

Without significant extra investment level (WEIL) of achievement can be defined as the fire risk level an organisation could achieve, right now, with existing resources and under existing constraints, if resources and technology were better organised. This is a fire risk level that an organisation is capable of achieving in each operation, given the limitations imposed on any operation or activity by other operations or activities of the organisation. The WEIL seems to reflect reality for the concerned organisation's operations or whole organisation, but may be restricted by some other parts of the organisation. Sometimes these restrictions may be called bottlenecks, and these bottlenecks may have to do with low operations capacities, or have to do with technological constraints. These considerations define two more levels of fire safety as described below.

Minor Extra-Investment Level

Minor extra investment level of achievement (MINEIL) can be defined as the fire risk level an organisation ought to be achieving, if a minor investment were made to eliminate some shortcomings in capacity or technology. This is a medium-term and relatively static level of achievement.

Major Extra-Investment Level

Major extra investment level of achievement (MAJEIL) can be defined as the fire safety level an organisation would be capable of achieving, if some major investment in new equipment, or new technology were made to eliminate current constraints. The MAJEIL is a long term and static level of achievement until the organisation's operations, or the organisation itself, has structurally changed.

The MAJEIL and the MINEIL of fire risk levels are better than the WEIL, and the WEIL in turn is better than the current fire risk level. The fire safety performance of an organisation cannot rise to its desirable level without some kind of investment. It cannot even rise to the WEIL unless resources and technology are well organised. The current fire safety performance is a continuous fluctuating value, since it represents risk arising from the continuous activities of an organisation's operations.

Fire Safety Plans

Fire safety can be planned according to the four risk levels of achievement as described above. This planning process is illustrated in Figure 5.2. Planning is understood here as a continuous process of decision-taking, whereby resource allocations are made, so that the organisation's future fire safety performance may be better. Fire safety should be planned to address both ICS and ECS for apparent and latent factors. Four kinds of fire safety plans are identified as below.

Operative Planning

Planning fire safety from the CAL is referred to here to as *operative* fire safety planning. In this kind of planning, there is no fire safety performance improvement or change, but it accepts the existing status of fire safety as it is in the organisation's operations.

Programmatic Planning

Planning fire safety from the WEIL is called here *programmatic* planning. This kind of planning sets new short term objectives for improving the fire safety performance and tries to achieve them. However, these objectives can be achieved without significant extra investment; that is, they can be achieved with essentially existing resources and under existing constraints.

Strategic Planning

Planning fire safety from the MINEIL is referred to here as *strategic* fire safety planning. It sets new medium-term objectives for fire safety performance improvement, but they can only be achieved with some minor investment to eliminate current constraints.

Normative Planning

Planning fire safety from the MAJEIL is termed *normative* planning. This planning process involves setting long-term fire safety objectives. To accomplish these fire safety objectives, organisations will need to commit major investment to develop new technologies, new equipment or processes. These plans may incur major economic risks, but also may offer major benefits for the organisation.

Fire Safety Indices of Performance

It can be seen from Figure 5.2 that the four levels of fire safety achievement are combined as three ratios to form short, medium and long term indices of achievement. Moreover, Figure 5.2 shows how these three indices are combined to create an overall fire safety performance index of the whole organisation. It should also be emphasised that these fire safety indices involve deriving indices for both ICS and ECS for apparent and latent factors. A detailed description of these indices is given as follows.

Short-term Index of Achievement

The ratio of the WEIL to the CAL is called *short-term index of achievement* (SIA). The SIA is a continual state of change index, since the CAL is understood as a fluctuating value and the WEIL, on the other hand, is a relatively steadier value.

Medium-term Index of Achievement

The ratio of MINEIL to the WEIL is referred to as the *medium-term index of achievement* (MIA). The MIA requires minor investment. This is a relatively static index, since the minor fire safety performance level is a medium-term fire safety goal.

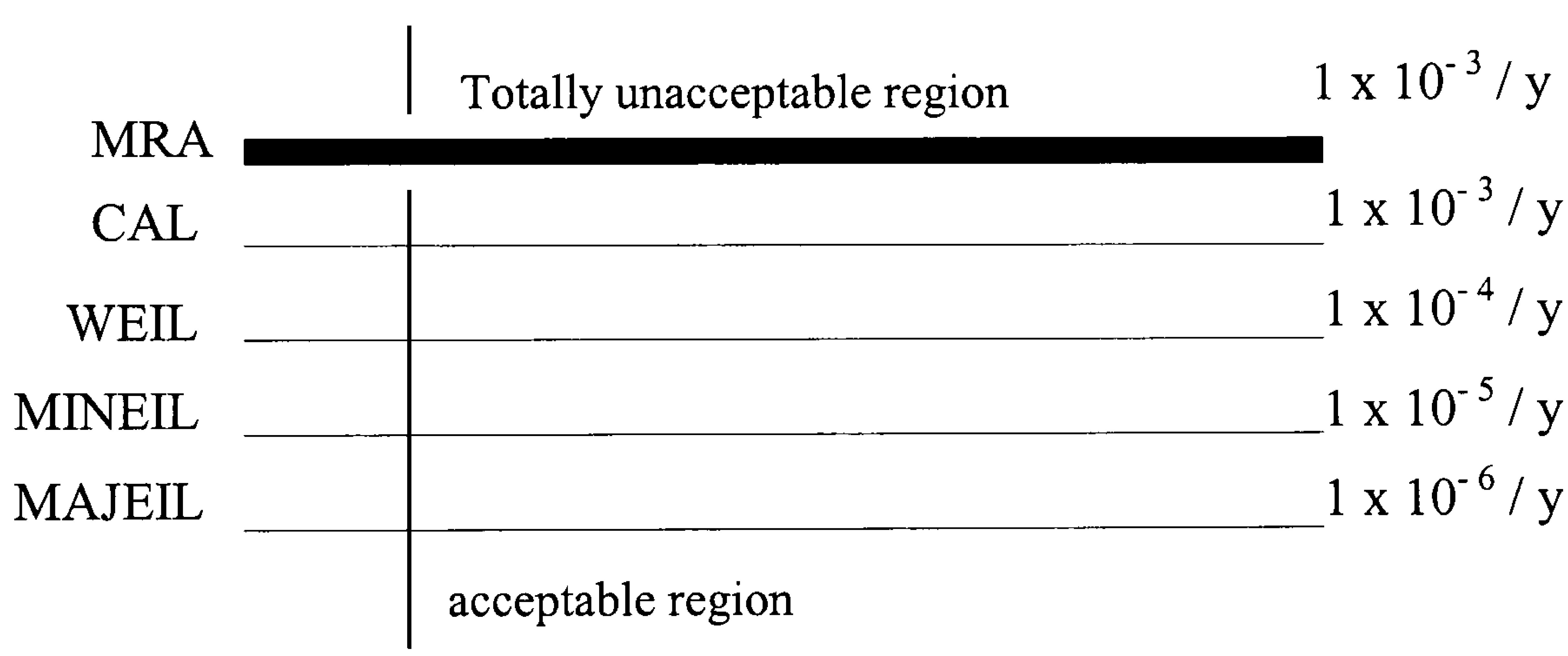
Long-term Index of Achievement

The ratio of the MAJEIL to the MINEIL is called *long-term index of achievement* (LIA). This index involves major investment. The MINEIL and the MAJEIL fire safety levels are static measures. The resulting index will also be relatively static.

Fire Safety Performance Index

The overall *fire safety performance index* (FSPI) of an organisation can be obtained by the ratio of the MAJEIL to the CAL, or by the product of the SIA, MIA, and LIA indices. It should be noted that the FSPI is determined by the CAL and the MAJEIL level, as being two extremes. This means that the WEIL and MINEIL are floating between them, so they can be changed without affecting the CAL or the MAJEIL.

Example:



Indices of Achievement

SIA = WEIL / CAL = $10^{-4} / 10^{-3} = 0.1$

MIA= MINEIL / WEIL = $10^{-5} / 10^{-4} = 0.1$

LIA = MAJEIL / MINEIL= $10^{-6} / 10^{-5} = 0.1$

Fire Safety Performance Index

FSPI = SIA x MIA x LIA = 0.1 x 0.1 x 0.1 = 0.001 = 0.1 %

5.3.3 The Structural Organisation and Its Communication and Control

It has long been known that an organisation's communication system has a significant impact on the organisation's performance. Also, it has been discussed elsewhere[12] that multiple distributed decision making is impossible without communication. Good decision making relies on well designed networks of 'real-time' information systems. Moreover, good communication systems may serve as a means of instilling and sustaining an organisation's safety culture. A typical problem associated with poor communication is lack of trust[77,78,79], and trust within organisations is a continuous process[80]. An organisational structure needs to be in place to ensure that this process is sustained throughout the organisation's life cycle. Organisations that require constant attention to safety should be characterised by an effective structural organisation in order to have a strong safety culture.

The structural organisation of the FSMS may help organisations to reduce problems associated with communication and control. As mentioned above, the FSMS model intends to address fire safety in an organisation in three levels of recursion, as shown in Figure 5.1. In this section, fire safety in an oil and gas organisation is used to describe in detail the structural organisation of the FSMS and its communication and control model. Figures 5.3, 5.4 and 5.5 show three levels of recursion of the structural organisation of the FSMS. Figure 5.6 shows the channels of communication and control of the FSMS.

System 1: Fire Safety Policy Implementation

The function of system 1 is to implement a fire safety policy. System 1 contains a set of subsystems or operations that deal directly with an organisation's business activities. These various operations or subsystems of system 1 are also responsible for implementing the organisation's fire safety policy. The number of operations that form part of system 1 will depend on the specific organisation being modelled. In this particular case, for example, an oil and gas field of three subsystems or operations called 1-BA, 1-BB, and 1-BC, form part of system 1. A particular operation, for example, 1-BA operation, could be an integrated production, drilling, and accommodation platform. It should be noted that each operation performs five functions, namely fire safety policy, development, functional, co-ordination, and implementation. This means that the FSMS for the oil and gas production system is replicated in each operation of system 1. An FSMS for a specific oil and gas offshore installation is illustrated in Figure 5.4.

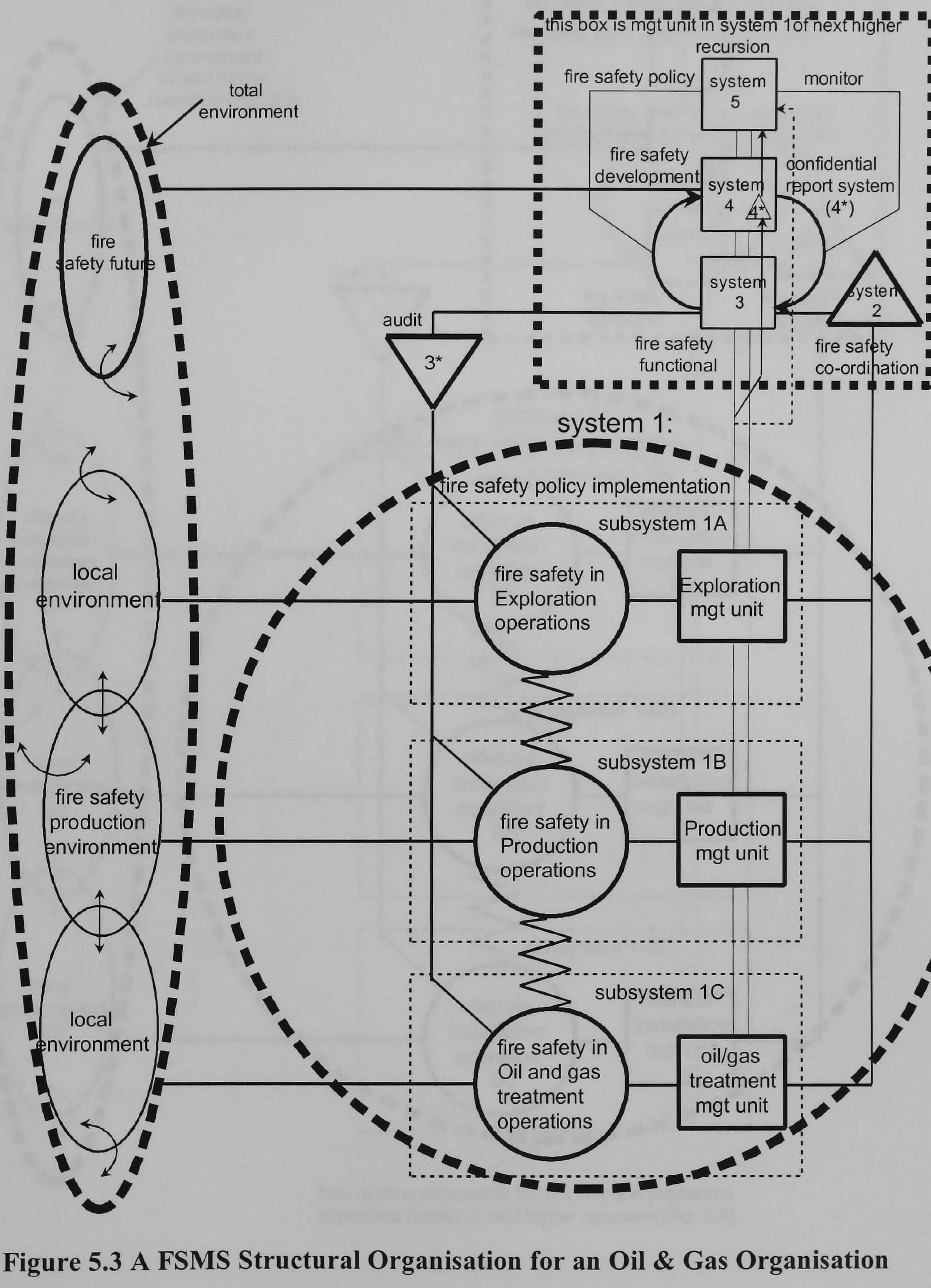


Figure 5.3 A FSMS Structural Organisation for an Oil & Gas Organisation

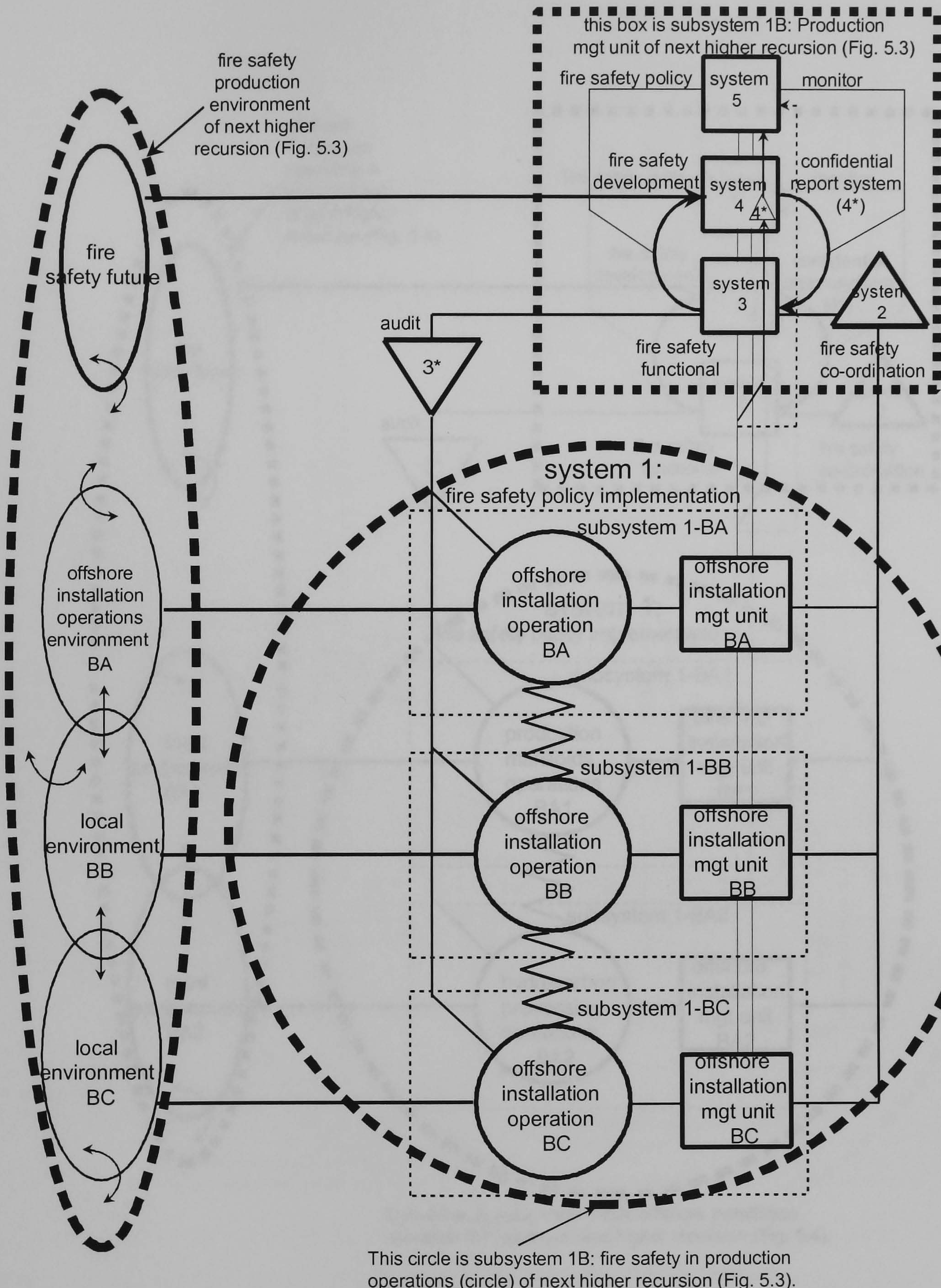


Figure 5.4 A FSMS Structural Organisation for an Oil & Gas Production Offshore Operations

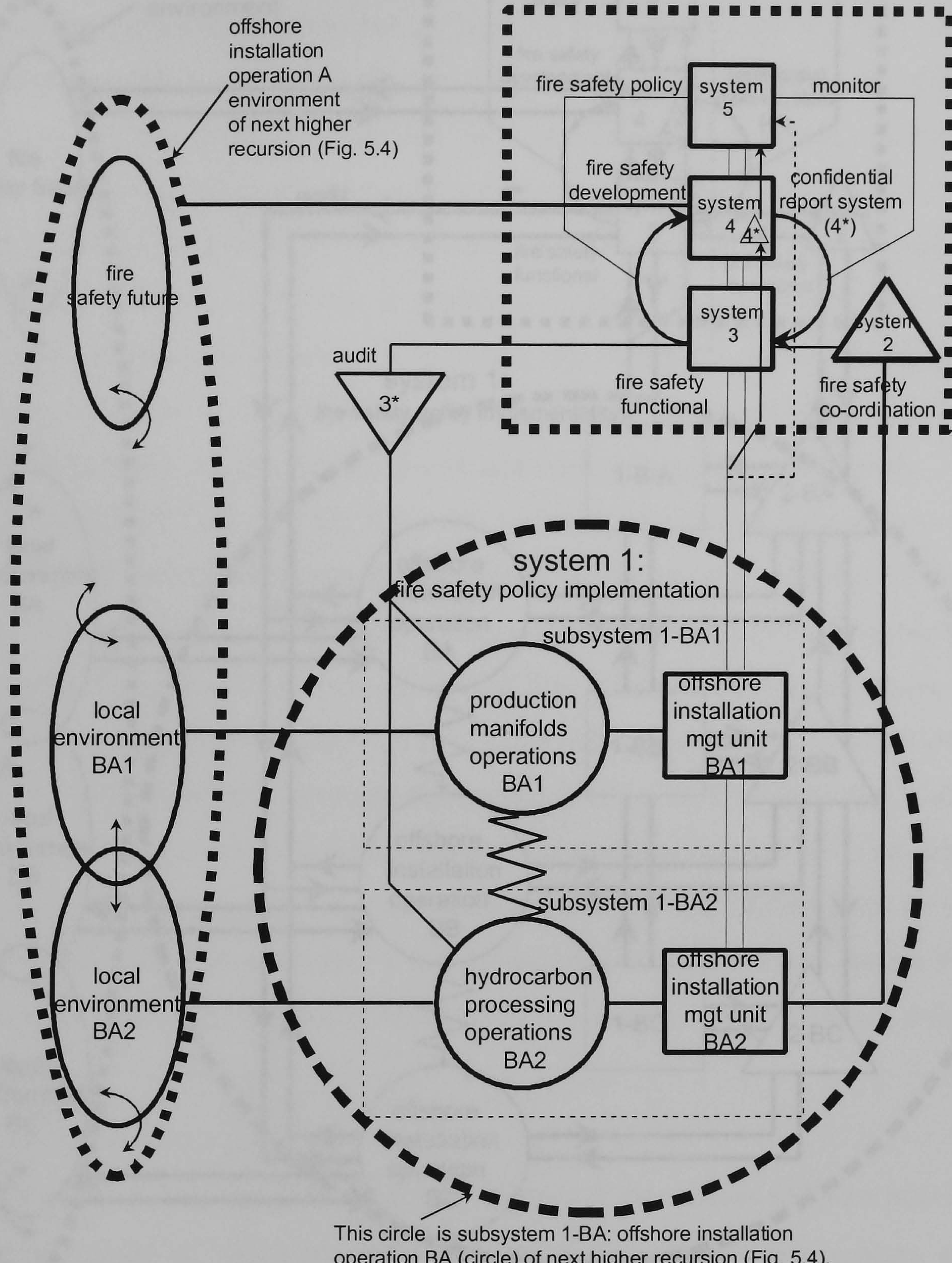


Figure 5.5 A FSMS Structural Organisation for a Particular Offshore Installation Operation - BA

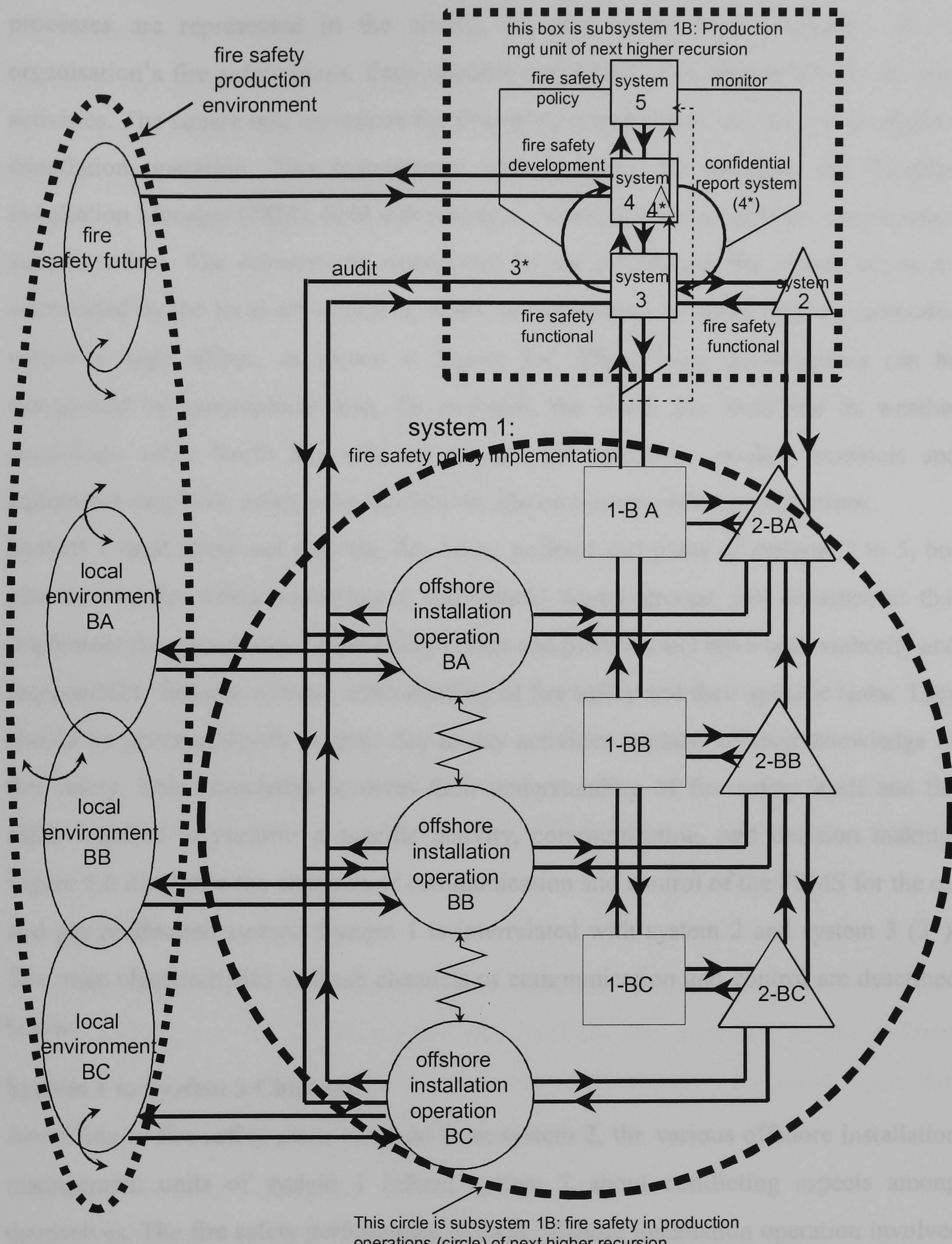


Figure 5.6 Channels of Communication & Control of an FSMS for an Oil & Gas Production Offshore Operation

Each operation of system 1 has a degree of interdependence with the other operations, as represented by the zigzag lines illustrated in Figure 5.3. Oil and gas production processes are represented in the circles, as well as the accomplishment of the organisation's fire safety plans. Each operation of system 1 is responsible for its own activities. The square box represents the fire safety management unit for every offshore installation operation. This management unit includes, for example, the Offshore Installation Manager (OIM), field unit manager, installation safety officers, maintenance superintendent. The sub-systems represented by the circles and the square boxes are surrounded by the local environment, which is represented by small ellipses embedded within a large ellipse, as shown in Figure 5.4. These local environments can be categorised by geographical area, for example, the North Sea itself and its weather conditions, other North Sea offshore oil and gas operators, market, materials and equipment suppliers, safety case regulations, and environmentalist organisations.

System 1 must know not only the fire safety policies and plans of systems 2 to 5, but also its own fire safety commitment. Individuals, teams, groups, and departments that implement the organisation's fire safety policy and plans should have both authority and responsibility because of their understanding of fire safety and their specific tasks. They should be given authority in their day-to-day activities because of their knowledge of fire safety. This knowledge involves their understanding of fire safety itself and the skills required to perform a specific activity, communication, and decision making. Figure 5.6 illustrates the channels of communication and control of the FSMS for the oil and gas production system. System 1 is interrelated with system 2 and system 3 (3*). The main characteristics of these channels of communication and control are described below.

System 1 to System 2 Channel

According to fire safety plans received from system 2, the various offshore installation management units of system 1 inform system 2 about conflicting aspects among themselves. The fire safety performance of each offshore installation operation involves both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

Externally committed systems involve the performance of the physical offshore installations. This performance may include, for example, production processes, communication systems, such as telecommunication facilities, an increase in oil and gas production, oil and gas import and export changes, process changes, maintenance programmes, and emergency shutdown systems (ESD).

Internally Committed Systems

Internally committed systems involve the employees who perform the offshore installation operations or activities. They include for example, the OIM, maintenance superintendent, installation safety officer, maintenance personnel, drilling, construction, production, operations, and support.

System 1 to System 3* Channel

To comply with the fire safety plans received from system 3*, the various offshore installation operations of system 1 inform system 3* about their performance. System 1 operations should report their performance with both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

Each offshore installation operation of system 1 should respond to the system 3*'s inquiry about the state of fire safety performance for apparent and latent factors of the physical offshore installation. This performance should include, for example, oil and gas-water separation systems, gas compression system, emergency shutdown systems (ESD), well control systems, communication systems, such as telecommunication facilities, fire and gas detection systems, active fire protection systems, and passive fire protection.

Internally Committed Systems

The offshore installation operations of system 1 should inform system 3* about the state of the performance of the employees who perform the activities in the offshore installation operations. This includes for example, maintenance personnel, operations supervisors, safety officers, inspectors, as well as suppliers.

System 1 to System 3 Channel

All fire safety plans received from system 3 by system 1 aim to maintain the fire risk substantially below the MRA in the subsystems or operations. The offshore installation management units of system 1 are responsible for meeting these fire safety objectives, and for informing system 3 whether the plans are being accomplished or not. System 1 accountability to system 3 should cover both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

The responsibilities of the offshore management units of system 1 are threefold. First, they are responsible for the performance of their physical offshore installation. This includes for example the performance of oil and gas-water separation systems, gas compression system, emergency shutdown systems (ESD), well control systems, communication systems, such as telecommunication facilities, fire and gas detection systems, active fire protection systems, passive fire protection, and the temporary refuge (TR). Second, they inform system 3 whether the planned fire safety performance of the physical offshore installation is being achieved or not. Finally, they inform system 4 of any fire safety issues of every offshore installation that arise in the offshore installation's local environment.

Internally Committed Systems

The offshore management units of system 1 should first be responsible for the performance of the employees who perform the activities in the offshore installations. This includes for example, maintenance personnel, production process personnel, safety officers, inspectors, as well as materials and equipment suppliers. Second, system 3 should be informed of whether the planned performance associated with these employees is being achieved or not. Finally, system 4 should be informed about both apparent and latent factors concerned with employees, suppliers, personnel from other oil and gas production installations, that arise in every offshore installation local environment.

System 1 to System 4* Channel

All fire safety concerns of the various operations of system 1 should be communicated to the independent system 4*. System 1 confidential reports should be enabled to cover both externally and internally committed systems for apparent and latent factors. These confidential reports are shifted by system 3 to system 4*.

Externally Committed Systems

System 1 operations should communicate fire safety concerns regarding the performance of their physical offshore installations. This includes for example the performance of oil and gas-water separation systems, gas compression system, emergency shutdown systems (ESD), well control systems, communication systems, such as telecommunication facilities, fire and gas detection systems, active fire protection systems, passive fire protection, and the temporary refuge (TR).

Internally Committed Systems

System 1 operations should also communicate fire safety concerns regarding the performance of the people who perform the activities in the offshore installations. This includes for example, maintenance personnel, production process personnel, safety officers, inspectors, as well as materials and equipment suppliers.

System 2: Fire Safety Co-ordination

The function of system 2 is to co-ordinate the activities needed to be implemented in the subsystems or operations of system 1, as illustrated in Figure 5.3. System 2 along with system 1 management units implements the programmatic fire safety plans received from system 3. System 2 is also in charge of developing operative fire safety plans and helps system 1 to implement them. Furthermore, it informs system 3 about routine information on the performance of the offshore installation operations. To accomplish the plans of system 3 and the needs of system 1, system 2 gathers and manages the fire safety information of the system 1 operations.

To achieve its function, System 2 must know not only the commitment of system 1, externally and internally, and system 3 fire safety plans, but also its own fire safety commitment. Individuals, teams, groups, and departments that contribute to performing the function of system 2, should have both authority and responsibility because of their understanding of fire safety. They should be given authority in their day-to-day activities by virtue of their knowledge of fire safety. This knowledge involves their knowledge of fire safety itself and the skills required to perform co-ordinated activities, communication, and to make decisions.

As illustrated in Figure 5.5, system 2 is interrelated with system 1 and system 3. The main characteristics of these channels of communication and control are described below.

System 2 to System 1 Channel

System 2, along with the various management units of system 1, develops, communicates, and co-ordinates the activities required to implement the fire safety plans received from system 3. These activities should cover both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

System 2 along with system 1 develops, communicates and co-ordinates the activities required to implement not only the fire safety plans for the physical offshore installations, but also oil and gas production plans. This includes for example, oil and gas production schedule, maintenance schedules, process changes, procedures for implementing a modification, and fire safety systems maintenance schedules.

Internally Committed Systems

System 2 and system 1 management units also develop, communicate and co-ordinate the activities required to implement the fire safety plans, received from system 3, for the offshore installation's employees. This should include the employees of every offshore installation operation. An example of such a fire safety plan could be the setting up of safety training programmes and schedules.

System 2 to System 3 Channel

System 2 complies with the fire safety plans received from system 3 by informing system 3 about all conflicting aspects arising from the activities of the operations of system 1. Routine information about the performance of all offshore installation operations should always be available from system 2. This information should involve both internally and externally committed systems for apparent and latent factors, as follows.

Externally Committed Systems

System 2 should inform system 3, according to system 3 plans, about all possible conflicting aspects among the various physical offshore installations of system 1. This includes, for example, conflicting aspects of exporting and importing of oil and gas from one operation to another operation of system 1. An example of this could be risers, gas and oil pipe lines that connect the system 1 operations.

Internally Committed Systems

System 2 should also inform system 3 about all possible conflicting aspects directly associated with the employees of the various offshore installation operations of system 1. An example of a conflicting aspect could be the lack of fire safety training, conditions of employment, or communication failures that may compromise the safety amongst the offshore installation operations of system 1.

System 3: Fire Safety Audit*

The function of system 3* is to conduct audits sporadically into the offshore installation operations of system 1. System 3* intervenes in the offshore installation operations of system 1 according to the fire safety plans received from system 3. System 3 needs to ensure that the accountability reports received from system 1 reflect not only the current status of the system 1 subsystems, but are also aligned with the overall objectives of the organisation. The audit activities should be sporadic. They may be less effective if they are conducted regularly or if they are anticipated. Audit activities should not be conducted too frequently or they may undermine the authority and trust of the management units of system 1. Therefore, they should be implemented under common agreement between system 3* and the management units of system 1.

System 3* must know the offshore installation operation's performance and the system 3 fire safety plans, as well as its own fire safety commitment. Therefore, individuals, teams, groups, and departments within system 3* should have both authority and responsibility by virtue of their understanding of fire safety. They should have authority in their activities by their knowledge of fire safety auditing. This knowledge involves that of fire safety itself and the skills required to perform effectively a specific audit activity, communication, and decision making.

As illustrated in Figure 5.5, system 3* is interrelated with systems 1 and 3. The main characteristics of these channels of communication and control are described below.

System 3* to System 1 Channel

System 3* identifies and inhibits the performance that does not conform with the planned fire safety objectives for the offshore installation's operations. It conducts its activities according to the fire safety plans received from system 3. System 3* should cover both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

System 3* should be able to identify and inhibit all possible performances that do not conform with the planned fire safety objectives for the physical offshore installations of system 1. This includes, for example, the state of oil and gas-water separation systems, gas compression systems, communication systems, such as telecommunication facilities, emergency shutdown systems (ESD), well control systems, communication systems, such as telecommunication facilities, fire and gas detection systems, active fire protection systems, and passive fire protection.

Internally Committed Systems

System 3* should also identify and inhibit all possible performances that do not agree with the planned fire safety objective associated with the offshore installation operation's employees. This includes for example, maintenance personnel, production and construction personnel, safety officer, inspectors, as well as suppliers.

System 3* to System 3 Channel

According to the fire safety plans received from system 3, system 3* informs system 3 about all possible performances that do not agree with the planned fire safety objectives for system 1. This report should include both internally and externally committed systems for apparent and latent factors, as follows.

Externally Committed Systems

System 3* informs system 3 about all performances that do not conform with the planned fire safety objectives for the physical offshore installations of system 1. This should include, for example, the state of oil and gas-water separation systems, gas compression systems, communications systems, such as telecommunication facilities, emergency shutdown systems (ESD), well control systems, fire and gas detection systems, active fire protection systems, passive fire protection.

Internally Committed Systems

System 3* should also inform system 3 about the performance that does not meet the planned fire safety objectives associated with the system 1 operations' work-force. It should be emphasised that this should include all activities and the employees themselves. For example, maintenance personnel, production processes personnel, safety officers, inspectors, as well as suppliers' performances should be audited.

System 3: Fire Safety Functional

System 3 is responsible for sustaining fire safety within an acceptable range in the subsystems or offshore installation operations of system 1. It achieves its function on a day-to-day basis according to its own plans and the strategic and normative fire safety plans received from system 4. The purpose of these plans is to anticipate and act proactively to maintain fire risk arising from the offshore installation operations of system 1 well below the MRA. System 3 requests from systems 1, 2, and 3* information directly related and not directly related to the fire safety performance of system 1 to formulate its programmatic fire safety plans. These plans are then communicated to systems 1, 2, and 3*. It is also responsible for allocating the necessary resources to system 1 to accomplish its fire safety plans.

System 3 has to know the performance of system 1 and the fire safety plans of system 4, as well as its own fire safety commitment to achieve its function. Individuals, teams, groups, and divisions that integrate to form system 3 should have both authority and responsibility because of their understanding of fire safety and their specific tasks. They should have authority in their day-to-day activities because of the knowledge of their specific activity and commitment to fire safety. This knowledge involves their knowledge of fire safety itself and the skills required to perform a specific activity, communication, and decision making.

As illustrated in Figure 5.5, system 3 has a direct relationship with its sub-system 3*, system 2, system 1, and system 4. The main characteristics of these channels of communication and control are given below.

System 3 to System 3* Channel

To comply with the fire safety plans of system 4, system 3 should communicate its fire safety plans to enable system 3* to conduct fire safety audits into the offshore installation operations of system 1. System 3 fire safety audit plans should address both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

System 3 should communicate to system 3* its fire safety plans to enable system 3* to conduct audits to know the current state of the physical offshore installations that integrate to form system 1. This includes, for example, the state of oil and gas-water separation systems, gas compression systems, emergency shutdown systems (ESD), well control systems, communication systems, fire and gas detection systems, active fire protection systems, and passive fire protection.

Internally Committed Systems

System 3 also communicates its fire safety plans to system 3* to enable it to conduct fire safety audits to know the current state of the knowledge of specific tasks and the commitment to fire safety of system 1 employees. This may include, for example, the employees' fire safety culture, competence, etc.

System 3 to System 2 Channel

System 3 requires system 2 to gather performance information from system 1 to set new plans, or communicate to system 4 about system 1 needs. It should be emphasised that the information gathered by system 2 is mainly concerned with routine information about the fire safety directly related and not directly related performances of the offshore installation operations of system 1. This routine information should include both internally and externally committed systems for apparent and latent factors.

Externally Committed Systems

System 3 requests from system 2 critical information that may compromise the fire safety of the physical offshore installations of system 1. This includes, for example, oil and gas pipeline systems, communication systems amongst the offshore installations, production process systems, fire fighting systems, fire and gas detection systems, etc.

Internally Committed Systems

Apart from the physical aspects of the offshore installations, system 3 requests from system 2 information related to each offshore installation's employees that may compromise the safety of the offshore installation operations. This should include, for example, the offshore installation operation's employees' decisions and their interactions with employees in other offshore installations.

System 3 to System 1 Channel

To accomplish the organisation's fire safety policy, system 3 communicates this policy as programmatic fire safety plans to system 1. System 3 should allocate the necessary resources to system 1 in order to implement its plans. This channel of communication and control should include both externally and internally motivated systems for apparent and latent factors.

Externally Committed Systems

System 3 should communicate the programmatic fire safety plans to system 1 to maintain an acceptable level of fire safety in the physical offshore installations. It also needs to allocate the necessary resources for the implementation of these plans. For example, these plans should address both the facilities of the production processes and the fire fighting systems.

Internally Committed Systems

Programmatic fire safety plans directed to maintain an acceptable level of fire risk concerning human aspects have to be communicated by system 3. System 3 also will have to allocate resources to accomplish these plans. For example, these plans should address those individuals dedicated to both the production processes and to fire safety.

System 3 to System 4 Channel

According to system 4 fire safety plans and the information received from systems 1, 2, and 3*, system 3 informs system 4 about the needs of system 1. This might be, for example, possible fire safety implications of process changes, or any need that requires new technology development. System 3 should communicate to system 4 the needs of system 1 in terms of internally and externally committed systems for apparent and latent factors.

Externally Committed Systems

System 3 communicates the needs of the physical offshore installations of system 1 so that system 4 can satisfy them. These needs may imply the development of new technologies, reassessment of process changes, new development of means of escape, development of fire safety models, etc.

Internally Committed Systems

All human aspects that need to be addressed will have to be communicated by system 3. This may include, for example, the development of new fire safety training aspects.

System 3 to System 4* Channel

Additionally, system 3 deals with special information flowing through the special channel, from system 1 to system 4*. System 3 must establish criteria to ensure that the confidentiality of ascending special reports from system 1 to system 4*, is maintained. System 3 shifts confidential reports, from system 1 to system 4* by including both internally and externally committed systems for both apparent and latent factors.

Externally Committed Systems

System 3 should establish criteria that ensure the confidentiality of the reports related to the physical offshore installation. System 3 must shift these confidential reports into system 4* so that system 4* can assess these reports and communicate them to system 4.

Internally Committed Systems

System 3 should also establish criteria to maintain the confidentiality and shift special reports that deal with human aspects in the operations of system 1.

System 4: Fire Safety Confidential Reporting*

The function of system 4* is concerned with confidential reports from system 1 or causes of concern that may or may not require direct and immediate intervention of system 5 into system 1. System 4* enables system 1 to report any cause of concern to system 4* in absolute confidentiality. These reports would be expected to be less effective if they are not conducted on a confidential basis. System 4* is part of system 4, but it must be as independent as possible in order to achieve its function effectively; it would be desirable for 4* to be outside the organisation altogether.

System 4* must know the operations of system 1 performance and the system 4 fire safety plans, as well as its own confidential reporting commitment. Individuals, teams, groups, and departments within system 4* should have both authority and responsibility because of their understanding of confidential reporting. They should have authority in their activities by their knowledge of confidentiality; this knowledge involves fire safety itself and the skills required to perform effectively a specific confidential report assessment.

As illustrated in Figure 5.3, system 4* is interrelated with system 1, through system 3, and system 4. These channels of communication have the characteristics below.

System 4* to System 1 Channel

System 4* should provide the necessary means to enable the operations of system 1 to report any cause of concern by guaranteeing total confidentiality to the report and reporter. System 4* activities should include the gathering of confidential information related to both externally and internally committed systems for apparent and latent factors.

Externally Committed Systems

System 4* should gather all possible information related to the fire safety performance of the physical offshore installations of system 1. This includes for example, the fire safety concern of the oil and gas-water separation systems, gas compression systems, communication systems, such as telecommunication facilities, emergency shutdown systems (ESD), well control systems, communication systems, such as telecommunication facilities, fire and gas detection systems, active fire protection systems, and passive fire protection.

Internally Committed Systems

System 4* should also gather all possible information related to the fire safety performance of the employees of the offshore installation operation. This includes, for example, maintenance personnel, production and construction personnel, safety officers, inspectors, as well as suppliers.

System 4* to System 3 Channel

System 4* in agreement with system 3 develops criteria to ensure the confidentiality of special reports communicated from system 1 operations. System 4* requests system 3 to shift confidential reports, which should include both internally and externally committed systems for apparent and latent factors, as follows.

Externally Committed Systems

System 4* should request system 3 to facilitate system 1 to report all fire safety concerns related to the physical offshore installations. This should include, for example, the fire safety performance, the oil and gas-water separation systems, gas compression systems, communications systems, emergency shutdown systems (ESD), well control systems, fire and gas detection systems, active fire protection systems, passive fire protection.

Internally Committed Systems

System 4* should also request system 3 to facilitate system 1 to communicate all fire safety concerns associated with the system 1 operations' work-force. For example, maintenance personnel, production processes' personnel, safety officers, inspectors, as well as suppliers' performances should be addressed.

System 4* to System 4 Channel

System 4* communicates the results of the assessment of the confidential reports received from system 1. These results must be communicated whilst preserving the confidentiality of the reports. These recommendations should include both internally and externally committed systems for both apparent and latent factors.

Externally Committed Systems

System 4* should communicate to system 4 the results of the assessment of the confidential reports related to the physical installations of the operations of system 1.

System 4* should also communicate to system 4 the results of the assessment of the confidential reports related to the people involved in the activities of the operations of system 1.

System 4: Fire Safety Development

Systems 1, 2, and 3 are dedicated to the process of sustaining an acceptable fire risk in the various offshore installation operations that integrate to form system 1 on a day-to-day basis. They adjust the fire safety performance of the offshore installation operations within an accepted framework and under established key fire safety performance variables. Nevertheless, the successful functioning of systems 1, 2, and 3 depends on the appropriate fire safety plans, strategic and normative, as developed by system 4. The FSMS for the oil and gas production system has a function concerned with research and development (R&D).

The function of system 4 is concerned with fire safety development. This function may be regarded as a part of effective oil and gas offshore production fire safety planning. System 4 achieves its function according to the fire safety policy of system 5. This means the ability of the FSMS to maintain an acceptable level of fire safety in the oil and gas production system. System 4 deals with strengths and weaknesses, opportunities and threats to the whole oil and gas offshore production system, as shown in Figure 5.3. System 4 should sense and respond appropriately to the various threats and opportunities identified in the oil and gas production system's total environment. There are two main fire safety issues which system 4 has to deal with regarding the total environment. First, the large broken line elliptic symbol represents the environment of the oil and gas production system, which also includes the collection of system 1 local environments. The total environment is characterised by the physical and socio-economic infrastructure into which an oil and gas offshore production system is embedded. There are various important characteristics that system 4 needs to consider from this infrastructure. This infrastructure can be segregated into physical, economic, and socio-political characteristics. Physical characteristics may be, for example, a specific oil and gas field in the North Sea or Gulf of Mexico, and weather conditions. Economic characteristics may include, for example, the North Sea oil and gas operators' market, other oil and gas operators, suppliers and contractors. Finally, socio-political characteristics may include, for example, regulations such as the Safety Case

Regulations, and environmental organisations. System 4 needs to pay attention not only to these characteristics, but also to changing technologies.

Second, system 4 should deal with the fire safety 'future environment'. The fire safety future environment is concerned with threats and opportunities for future development affecting fire safety that may be relevant for the oil and gas production offshore system. Therefore, the FSMS deals not only with current fire safety problems, but also anticipates or prevents possible fire related accidents. All relevant needs or requirements of the organisation's environment are dealt with in system 4 and communicated to system 5. System 4 also deals with current system 1 needs and its potential future requirements as reflected in the system 1 local environments. System 3 communicates to system 4 all relevant needs of the existing performance of system 1 operations. Furthermore, system 3 should make clear the difficulties with which the existing performance of system 1 will be faced in trying to assimilate new fire safety developments that do not conform to the existing fire safety technology and the established fire safety culture. Finally, System 4 communicates confidential information, received from system 4*, to system 5. This information may require system 5 to intervene directly into system 1 operations.

In summary, system 4 first deals with the fire safety policy received from system 5. Second, it senses all relevant threats and opportunities from the total FSMS environment, including the fire safety future environment. Third, system 4 deals with all relevant needs of system 1 performance, and its potential future. Finally, it deals with the 'alarming' or special fire safety information communicated by system 4*. It has long been known that complex systems, such as an oil and gas organisation, may become disordered and disorganised[153] with time. System 4 activities are vital to the prevention or anticipation of these retrograde changes.

System 4 must understand the fire safety commitments of systems 1, 2, 3, 4* and 5, as well as its own commitment to fire safety. Individuals, teams, groups, and departments within system 4 should have both authority and responsibility because of their understanding of fire safety and their specific activities. They should be given authority in their day-to-day activities by their knowledge of fire safety and its future potential. This knowledge involves their knowledge of fire safety itself and the skills required to develop new technology, communication and decision making. It has been discussed elsewhere[154], for example, that fire safety models in a decision-making process must have the potential to assist decision makers in gaining a better understanding of a fire situation. Moreover, fire safety models should be employed in a responsible and acceptable way, and decision makers must be knowledgeable about the models and fire behaviour.

As illustrated in Figure 5.3, system 4 interacts with the total environment, system 4*, system 5, and system 3. The main characteristics of these channels of communication and control are described below.

Fire Safety Production Environment to System 4 Channel

System 4 deals with both the fire safety production environment and the fire safety future of the oil and gas production system. It senses all possible threats and opportunities arising from these two environments and communicates them to system 5. System 4 should address both internally and externally committed systems for apparent and latent factors in this channel of communication and control.

Externally Committed Systems

According to the organisation's fire safety policy received from system 5, system 4 identifies threats and opportunities regarding the physical oil and gas offshore production system. For example, system 4 should identify current and possible new regulations, such as the Safety Case regulations. It should understand the trends in new technology regarding the design of offshore platforms. This new technology may include an inherently safer design, which addresses fire safety in an early design phase of an offshore platform.

Internally Committed Systems

System 4 should also identify threats and opportunities regarding the employees of the whole oil and gas production system to satisfy the organisation's fire safety policy. Ergonomics in the offshore installation platform design, regulations related to human aspects, liability, insurance, contractors and suppliers may be some factors that need to be addressed in this channel of communication.

System 4 to Fire Safety Production Environment Channel

System 4 responds not only proactively to the threats and opportunities presented by the total oil and gas production system environment, but also has to influence its environment by attempting to allow for both foreseen and unforeseen threats and opportunities. By doing so, system 4 should include both internally and externally committed systems for apparent and latent factors.

Externally Committed Systems

To accomplish the organisation's fire safety policy, system 4 should respond proactively to the threats and opportunities regarding the physical oil and gas offshore production system. This may include the design or redesign of offshore platforms through inherently safer design principles, life cycle engineering principles, or by designing an effective fire safety management at the very earliest phase of the design process.

Internally Committed Systems

System 4 should respond proactively to the identified threats and opportunities regarding the employees of the whole oil and gas production system. This could include, for example, the continuous improvement of the organisation's safety culture, such as on- or off- site fire safety training.

System 4 to System 5 Channel

According to the fire safety policies of system 5, system 4 presents to system 5 the strategic and normative fire safety plans that characterise strengths and weaknesses, opportunities and threats to the organisation. These fire safety plans are then deliberated by system 5. According to system 4* recommendations, system 4 also presents to system 5 special fire safety plans that may need a direct intervention of system 5 into system 1. System 4 should take into consideration both internally and externally committed systems for apparent and latent factors when developing fire safety plans.

Externally Committed Systems

System 4 communicates strengths, weaknesses, threats, and opportunities to system 5 regarding the physical oil and gas production system. System 4 could, for example, communicate to system 5 whether the fire safety policy has been achieved or not and whether this policy responded to or complied with the identified needs and requirements of the organisation's environment.

Internally Committed Systems

System 4 communicates to system 5 the strengths, weaknesses, threats and opportunities regarding the employees of the whole oil and gas production system. System 4 could, for example, communicate to system 5 whether the fire safety culture policy has been achieved or not and whether this policy responded to needs identified in the organisation's environment.

System 4 to System 4* Channel

System 4 communicates to system 4* the organisation's commitment to the confidentiality of the special reports received from system 4*. This commitment should include both internally and externally committed systems for apparent and latent factors.

Externally Committed Systems

System 4 should communicate to system 4* the organisation's commitment to deal with confidential information related to physical installations of system 1 operations.

Internally Committed Systems

System 4 also should communicate to system 4* the organisation's commitment to deal with confidential information related to people who carry out system 1 operations' activities.

System 4 to System 3 Channel

System 4 communicates the fire safety policy received from system 5 to system 3. This elucidates future fire safety prospects, which the whole oil and gas production system is expected to confront. Moreover, system 4 should elucidate the threats and opportunities which it considers that the whole FSMS will face. This fire safety policy should address both internally and externally committed systems for apparent and latent factors, as follows.

Externally Committed Systems

System 4 communicates the fire safety policy to system 3 which will elucidate future fire safety prospects that the physical oil and gas production system is expected to confront. This fire safety policy should particularly elucidate future prospects about the strengths, weaknesses, threats, and opportunities about the existing fire safety performance, which involve both apparent and latent factors of the oil and gas production system.

Internally Committed Systems

System 4 also communicates the fire safety policy to system 3 that will elucidate future prospects that the employees of the oil and gas production system are expected to confront. Furthermore, the organisation's fire safety policy should elucidate future prospects concerning the strengths, weaknesses, threats, and opportunities, which it considers that the existing employees will have to face.

System 5: Fire Safety Policy

The function of system 5 is to deliberate fire safety policies and to make normative decisions. According to alternative fire safety plans, strategic, normative and special, received from system 4, system 5 deliberates and chooses feasible alternatives, which aim to sustain the viability of the whole oil and gas offshore production system. The purpose of these fire safety policies is to maintain an acceptable level of fire safety in the whole oil and gas production system. Furthermore, these fire safety policies reflect the fire safety values and beliefs of the whole oil and gas production system. System 5 also monitors the interaction, as depicted by the balancing loop connecting systems 4 and 3 shown in Figure 5.4 and Figure 5.6.

The people involved in system 5 must know not only the fire safety commitment of the people involved in systems 1, 2, 3 and 4, but also their own fire safety commitment. Therefore, individuals, teams, groups, and departments within system 5 should have both authority and responsibility because of their understanding of fire safety culture. They should be given authority in their day-to-day activities by their knowledge of fire safety. This knowledge involves their knowledge of fire safety itself and the skills required to deliberate policies, communicate effectively, and to make decisions regarding internally and externally committed systems for apparent and latent factors.

Externally Committed Systems

The fire safety policies that are considered and decided by system 5 for implementation should address the anticipation of fire accidents in physical oil and gas offshore production installations. These policies should also address principles of fire protection in the existing or new offshore oil and gas production systems.

Internally Committed Systems

The fire safety policies deliberated and decided by system 5 for implementation should reflect the needs of the employees of the whole offshore oil and gas production system about directly related and not directly related fire safety issues. It should also promote fire safety culture throughout the organisation.

The FSMS presented in this section is intended to help an organisation to manage fire safety in a coherent way. This means the various operations of the organisation can be treated as both vertically and horizontally interdependent. For example, a typical oil and gas company consists of exploration, production, and oil and gas treatment divisions, and these in turn consist of more specific operations and departments. As can be seen from Figure 5.4 and Figure 5.6, the various operations of system 1 are viable systems themselves; they consist of five subsystems labelled as systems 1 to 5. The organisation being focused on is an operational element of system 1 of a next higher level of recursion. For example, as can be seen in Figure 5.4, the FSMS for an oil and gas production sub-system is an operational element of system 1 of the FSMS for the oil and gas organisation as a whole. Similarly, the level of recursion next below can be modelled. Figure 5.5 depicts an FSMS for an oil and gas offshore installation that is embedded in the FSMS for oil and gas production offshore.

The various operations of system 1, subsystems 1A, 1B and 1C, as illustrated in Figure 5.3 and Figure 5.6, are horizontally interrelated. These operations are integrated and guided by systems 2 to 5. The interrelationship amongst the operations of system 1 may be strong or weak. However, the operations of system 1 should be given as much autonomy as possible in order to achieve fire safety policies more effectively. Systems 2 to 5 will intervene in system 1 operations only to ensure the achievement of the organisation's fire safety policies.

Fire safety commitment and responsibilities are distributed throughout the whole organisation. System 5, fire safety policy, is committed and responsible for establishing fire safety policies for the whole organisation. System 5 is aided by system 4, which is responsible for fire safety development. System 4, considering strengths, weaknesses, opportunities and threats, suggests changes to the existing fire safety policies. It should be emphasised again that the operations of system 1 should possess as much autonomy as possible in order to implement fire safety policies more effectively. Fire safety commitment should be emphasised at the operations of system 1, so that systems 2 to 5 can concentrate on their own functions. Fire safety information flow is also emphasised in the FSMS for more effective fire safety planning. Finally, the FSMS incorporates a system which may facilitate the measurement of the organisation's fire safety performance. This fire safety measurement system consists of four kinds of fire safety achievement levels, four kinds of fire safety plans, and four kinds of fire safety achievement indices.

5.4 A Fire Safety Configuration Space

Figure 5.7 shows a framework called a 'fire safety configuration space' onto which organisations can be mapped to describe their safety performance. It suggests two regions, namely acceptable and unacceptable regions. The dividing line between these two regions is at the level of the Maximum Risk Acceptable (MRA). However, to be below the MRA, whilst nominally 'acceptable', would not be regarded as 'very acceptable'. An organisation should aim to be well below the MRA. The totally unacceptable region is characterised by those organisations or individuals that have very poor fire safety performance; this is a region of high vulnerability to fire incidents or accidents. ECS can be said to be typical systems that pertain to this region. To locate an organisation in the configuration space, it should be possible to identify a group of situations, for example, at **A**, specifying in each case the parameters which locate **A** in the space. If these parameters can be gathered, then one should be able to devise a measure of performance in **A**. Looking at it as a whole, the organisation has a very poor fire safety performance at **A** in the fire safety configuration space, as illustrated in Figure 5.7. Organisations located in this region may be said to be highly "vulnerable" to fire incidents. The acceptable region in contrast suggests that individuals, organisations or systems located in this region are very committed to fire safety and address fire safety pro-actively. To move to and remain in the acceptable region, organisations must take into consideration the ICS and ECS for both immediate and latent factors. Furthermore, they will need to adopt a systemic approach to manage their fire safety, as well as a systemic approach to quantify their fire safety performance as discussed in sections 5.3.2 and 5.3.3.

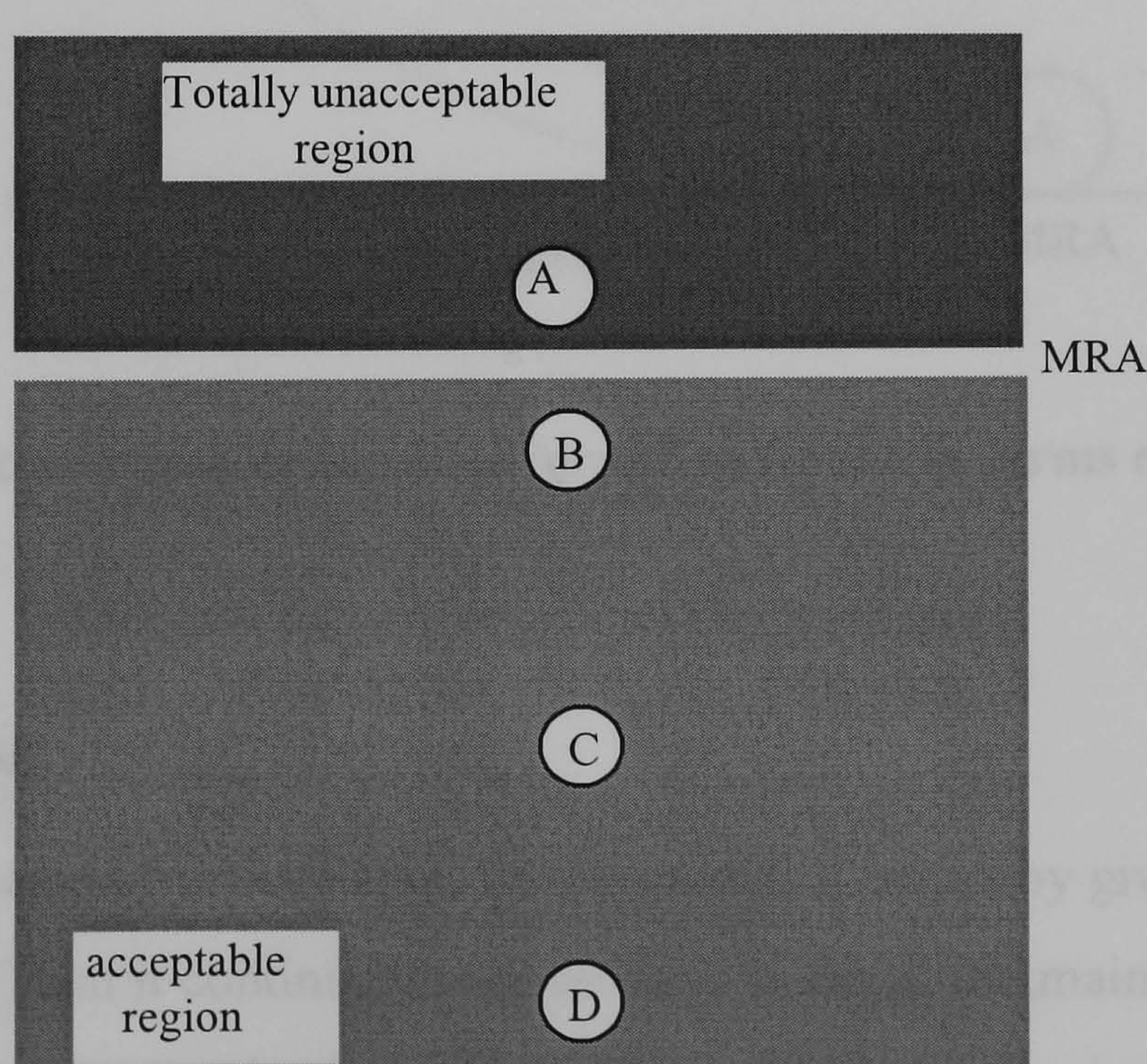


Figure 5.7 A Fire Safety Configuration Space

As an example, an organisation's state or situation at **A** can be understood as a set of parameters or variables that will need to be improved. According to Figure 5.7, the organisation's state at **A** must be changed to state **B**, which is defined as a less unacceptable state. It can hardly be said to be a very acceptable state, because its fire safety performance is still very poor. Then the organisation might move to states **C** and **D**. An organisation's fire safety performance could probably not be improved dramatically from one instant to another. As can be seen in Figure 5.7, organisations can reach an acceptable fire safety performance by state **D**. Organisations should aim to "navigate" [7] well below the MRA in the configuration space.

The fire safety configuration space might be thought of in terms of Fuzzy Set Theory[155]. This is because, e.g., whilst the state B is in the 'acceptable' region, it is not 'very acceptable'. One might envisage a graph of the kind in Figure 5.8, which shows a membership function, μ, for the set of 'Acceptable Risk Levels'. This indicates a possible area of further research.

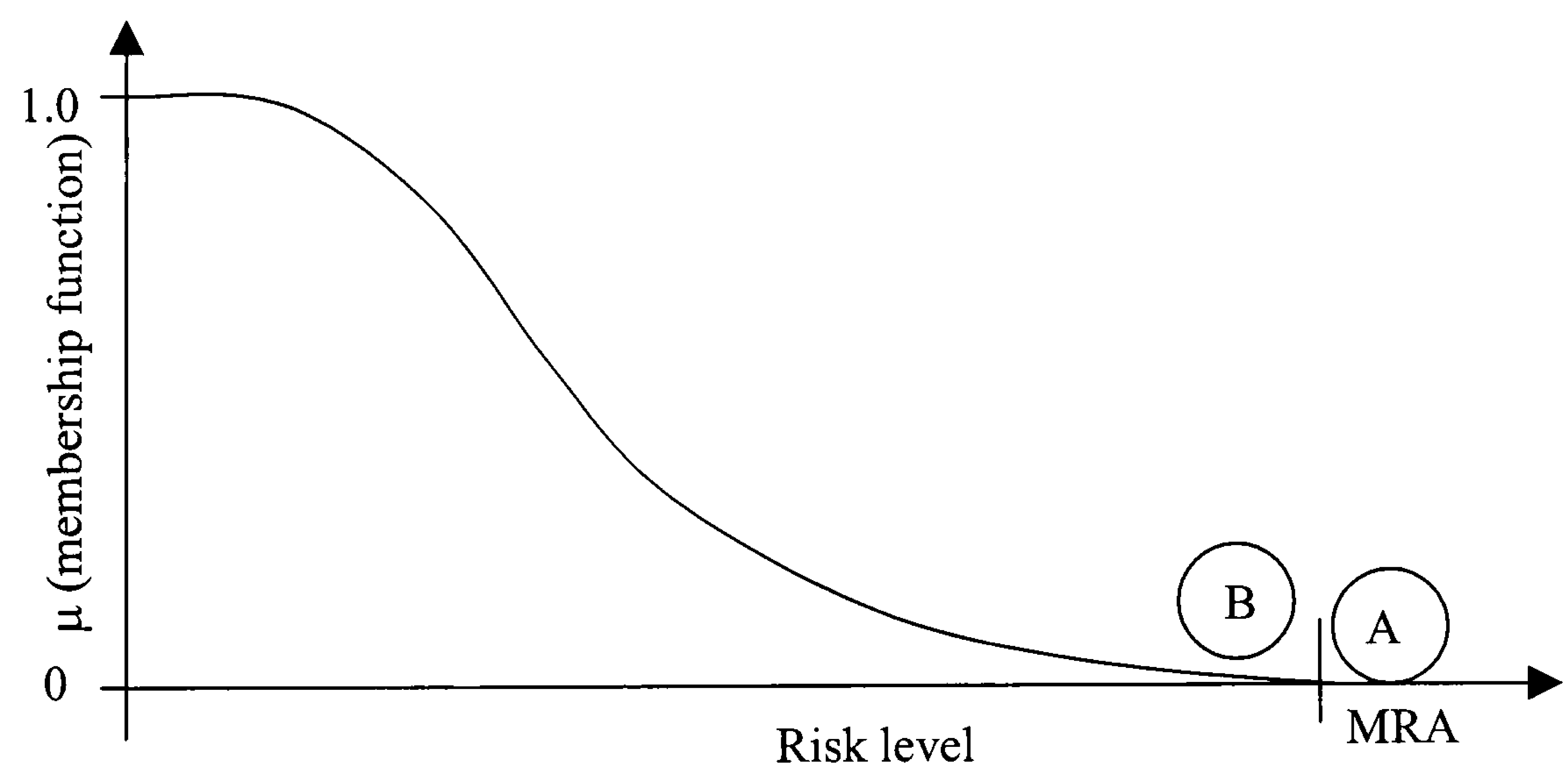


Figure 5.8 Representation of the Configuration Space in terms of μ and risk level

5.5 Conclusion

This chapter has presented the developed FSMS model. It began by giving an overview of the FSMS model. Then it continued by describing in detail the main aspects, such as the recursive structural organisation, the structure and its environment, and the communication and control aspects of the FSMS model. Then it proceeded by describing a space called the 'fire safety configuration space' that is intended to help organisations to map their fire safety performance. Finally, chapter 6 describes evaluation in relation to the FSMS model.

Chapter Six

Evaluation And the FSMS Model

6.1 Introduction

Chapter five presented a FSMS model which has been developed and proposed in this research project. This chapter discusses the evaluation of the FSMS model. Section 6.2 discusses some problematic aspects that prevented a full evaluation of the FSMS model. It also suggests some alternative ways to partially evaluate the FSMS. The FSMS has been compared with some existing SMSs. The results of this comparison are presented in section 6.3. Finally, the conclusion of this chapter is given in section 6.4.

6.2 Evaluation and the FSMS Model

This section discusses some major problematic aspects that prevented the researcher being able to fully evaluate the FSMS model. The Chambers Encyclopedic English Dictionary[157] defines Evaluation as:

"an estimate of value or worth"

Evaluation is understood here as an estimate of value or worth of the FSMS model for maintaining an acceptable fire risk in an organisation's operations life cycle. According to Checkland and Holwell[104]

"The scientific method can be expressed as being based on three fundamental principles which characterised it and give it its power: reductionism, repeatability, and refutation. Scientists select a portion of the world to investigate and carry out disciplined observations in experiments. If the results of the experiments are repeatable, they count as part of the body of knowledge; and progress can be made in sequences or experiments through the testing to destruction of hypotheses. Scientific knowledge is then the accumulation of hypotheses which have not (yet) been refuted."

However, as emphasised by Checkland and Holwell:

"things are more volatile in the investigation of human and social phenomena. There it is still necessary to argue about the underlying assumptions, the modes of inquiry, and their validity."

Given this context, it has not been possible to show fully the validity of the FSMS model. The traditional hypothesis-testing process was not adopted to conduct the research project, because this research addressed human and socio-technical phenomena. A research problem and questions process was adopted instead of the hypothesis-testing process as discussed in chapter one. Furthermore, it has not been possible to evaluate fully the effectiveness of the FSMS model, because the FSMS is the result of a systemic approach. The FSMS is highly complex, probabilistic and self-regulated. The FSMS has five interrelated and interactive subsystems which interact with its local and wider environments. These subsystems are arranged in a recursive structure that enables communication and control. The interaction of the subsystems and the behaviour of each subsystem are probabilistic; thus the behaviour of the FSMS as a dynamic whole is highly probabilistic. Moreover, the subsystems and the organisational structure of the FSMS have the purpose of maintaining risk within an acceptable range. Regarding the interrelated and interactive subsystems, the recursive structural organisations, the degree of autonomy, the interaction of this structure with its local and wider environments, and the channels of communication and control, any attempt to evaluate the FSMS model as dynamic whole would be impossible. The only way that it could be fully evaluated is through its implementation in real life. However, these characteristics of the FSMS model are themselves the basic criteria that define not only the FSMS, but also its effectiveness in maintaining an acceptable level of fire safety.

Regarding the research problem and questions, as discussed in section 1.2 from chapter one, it is possible to show the value and worth of the FSMS, though this may count as partial. If the FSMS model contains the basic criteria that define it and its effectiveness, then the ways below can be used to elucidate some of the characteristics of the FSMS model.

- compare with existing SMSs,

- probabilistic computer simulation,
- expert opinion, and
- take part in a real situation.

Comparing with existing SMSs and conducting a probability computer simulation are reported in sections 6.3 and 6.4 respectively. The FSMS model may be partially evaluated through the opinion of experts, which may include HSE, European Process Safety Centre (EPSC), practitioners, and renown researchers in the field. Another possible way of evaluating partially the FSMS could be for the researcher to participate in a specific real situation to assess the organisation's existing SMS and to try to shed light on the FSMS model. More detail of possible future work is given in section 7.7 in chapter seven.

6.3 Comparison with Existing SMSs

The FSMS was mapped to well-known and well-established safety management standards and SMSs. These mappings worked well because the FSMS describes a logically consistent and effective means for managing fire safety. This assessment process drew examples of SMS from the oil and gas industry to show the value of the FSMS model. Two main domains have been selected to accomplish the assessment process. First, a systemic approach, such as the Failure Paradigm Method (FPM) discussed in chapter three, was mapped to the FSMS prototype to identify strengths and vulnerabilities. This initial process is reported in chapter four. Second, well-established SMSs and standards in the oil and gas industry were selected to be mapped onto the final FSMS model to complete the process. The results of these mappings are reported in section 6.3. The 'Successful Health and Safety Management' HS(G)65[119], the British Standard 8000 (BS 8800)[58] 'Occupational Health, Safety and Environmental Management System', the 'European Safety Process Centre (ESPC) Management System'[116], were selected as three relevant standards to be mapped onto the FSMS model. Additionally, two North Sea Operators SMSs, namely Total Oil Marine (TOM)[158] and Conoco Limited (CUKL)[159] Safety, Health and Environmental (SH&E) Management Systems, were also mapped to the FSMS model.

In these mappings, the words and formats used in the original books and papers were used. Sometimes these words made the mapping obvious. However, at other times, these words made the mapping difficult because different people think, perceive and use words differently. The mappings presented here were based on the researcher's interpretation of the original author's intentions. The following paragraphs present some relevant results of these mappings.

6.3.1 The "Successful Health And Safety Management"

Table 6.1 maps the FSMS model to the "Successful Health Safety Management", HS(G)65, proposed by the Health and Safety Executive[119]. The HS(G)65 has six key functions, namely policy, organising, planning and implementing, measuring and reviewing performance, and auditing, that are linked to form a closed loop, as shown in Figure 6.1. Industry 'best practice' is suggested in the HS(G)65 to achieve each function successfully.

'Policy' involves communicating throughout an organisation the intentions, approach and objectives, and the criteria and principles on which the organisation's actions and responses are based. Health and safety policies should be comprehensive in order to contribute to the organisation's business performance, while complying with regulations, as well as meeting people's and environmental needs. Moreover, these policies should be effectively implemented and considered in all business practice and decision making. 'Organising' involves 'designing and establishing responsibilities and relationships' between individuals who achieve the organisation's activities. This should lead organisations to establish, operate and maintain structures and systems which aim at ensuring control, encouraging co-operation of employees and safety representatives, ensuring effective communication, and encouraging competence. This is helped by the creation of a safety culture that ensures motivation, involvement and participation of people at all levels. 'Planning' involves establishing objectives and methods of implementing the organisation's health and safety policy. It is concerned with allocating resources and deciding priorities and setting objectives with the aim of eliminating and controlling risks.

Performance standards should be established and performance is measured against them. 'Measuring performance', which involves a variety of checking and monitoring activities, is concerned with the collection of information about the implementation and effectiveness of the organisation's plans and standards.

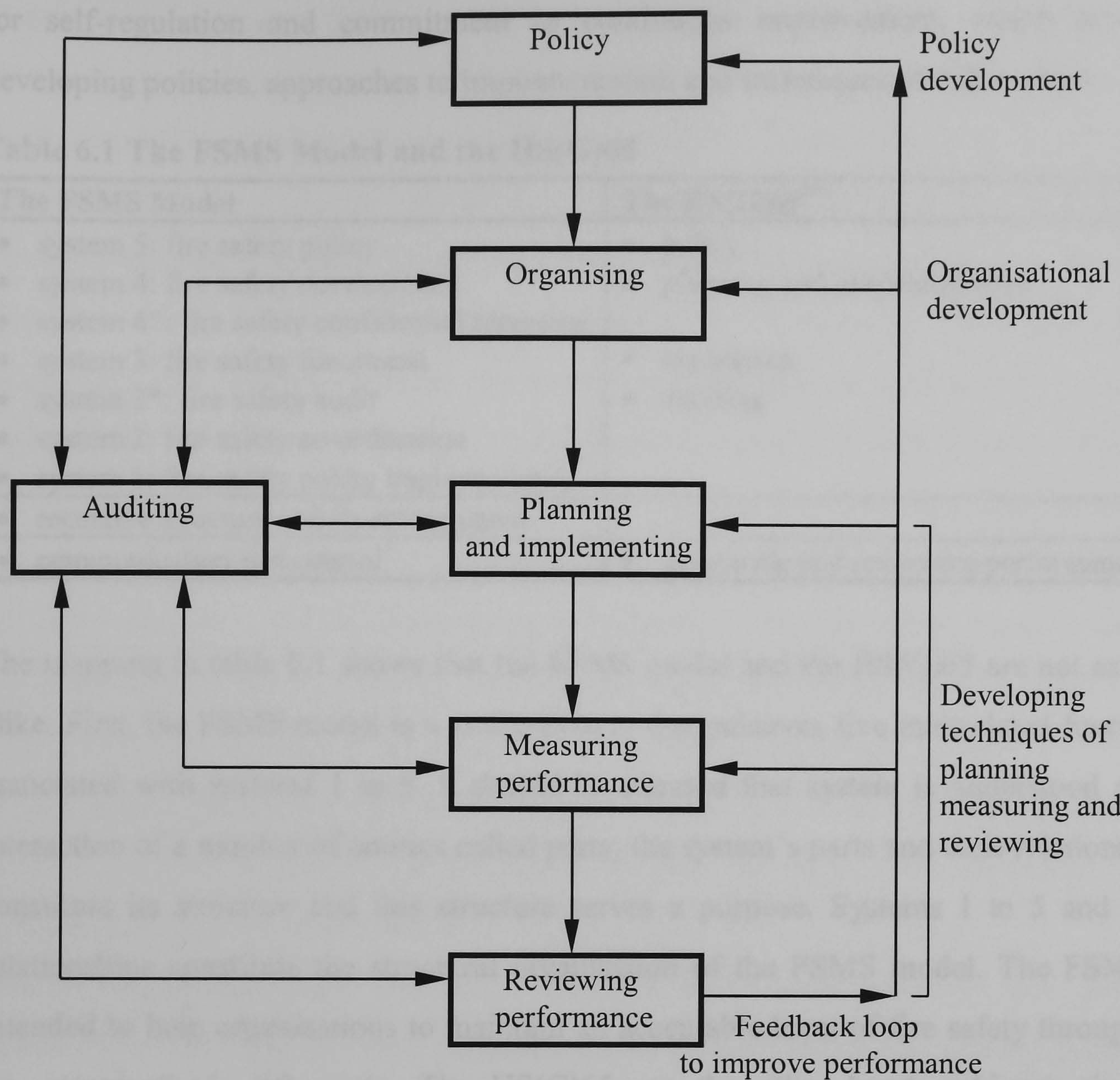


Figure 6.1 The Successful Health And Safety Management[119]

Organisations should assess their performance against pre-determined plans and standards; this can help them to establish, operate and maintain systems which ensure that their performance is assessed "objectively". 'Measuring performance' includes "active" monitoring systems to assess the success of plans, and failures of control are assessed by "reactive" monitoring systems, which require investigation systems, and reporting and response systems. 'Auditing' involves collecting independent information on the efficiency, effectiveness and reliability of the organisation's total SMS and developing plans for corrective action. 'Reviewing' describes activities that an organisation can use to judge its performance, and make decisions about improving performance, and to further develop its health and safety policies. Organisations need to review regularly their performance based on data from both monitoring activities and from auditing activities. It is stressed in the HS(G)65 that this function forms the basis for self-regulation and commitment to continuous improvement, which involves developing policies, approaches to implementation and techniques of risk control.

Table 6.1 The FSMS Model and the HS(G)65

The FSMS Model	The HS(G)65[119]
• system 5: fire safety policy • system 4: fire safety development • system 4*: fire safety confidential reporting • system 3: fire safety functional • system 3*: fire safety audit • system 2: fire safety co-ordination • system 1: fire safety policy implementation	• policy • planning and implementation • organising • auditing
• recursive structure and its environment	
• communication and control	• measuring and reviewing performance

The mapping in table 6.1 shows that the FSMS model and the HS(G)65 are not exactly alike. First, the FSMS model is a viable system that achieves five interrelated functions associated with systems 1 to 5. It should be stressed that system is understood as an interaction of a number of entities called parts; the system's parts and their relationships constitute its structure and this structure serves a purpose. Systems 1 to 5 and their relationships constitute the structural organisation of the FSMS model. The FSMS is intended to help organisations to maintain an acceptable level of fire safety throughout the organisation's life cycle. The HS(G)65, on the other hand, achieves six key functions, but it does not achieve explicitly the functions of system 4*, system 2, and system 1. Also, although the HS(G)65 has some parallel functions with the FSMS subsystems, the functions of these subsystems are fundamentally distinct. System 5 deliberates and makes normative decisions about fire safety policies, as well as monitoring the internal and external demands, as represented by the needs of system 3 and system 4 respectively. On the other hand, the HS(G)65 policy is used to communicate the organisation's commitment to health and safety throughout the organisation. System 4 continuously develops fire safety plans for the whole organisation. By considering strengths, weaknesses, threats, and opportunities, system 4 can suggest changes to the organisation's fire safety policies to adapt to the needs of the local and wider socio-economic and physical environment. The planning and implementation function of the HS(G)65 does not deal explicitly with an organisation's local and wider socio-economic and physical environment. Moreover, the HS(G)65 has no function that deals with confidential and special reports, though these aspects are discussed in measuring the performance function. The confidential reporting function can be achieved through system 4* of the FSMS model. System 4* is concerned with confidential fire safety reports, received from systems 1, 2 and 3, that may require direct intervention of the corporate management. The organising and the auditing function of the HS(G)65 follow closely the system 3 and system 3* functions of the FSMS model. The organising function designates responsibilities to achieve the organisation's objectives. The auditing function checks the effectiveness of the SMS by collecting independent information. System 3, on the other hand, ensures that system 1 implements the organisation's fire safety policies, as well as ensuring that fire safety is maintained at an acceptable level. System 3* is concerned with the fire safety sporadic audit. The HS(G)65 does not explicitly describe a co-ordination function either, hence it lacks a fire safety policy implementation function. As mentioned above, system 2 achieves a vital function in the FSMS that ensures that the various operations of system 1 operate in agreement. System 1 consists of the various operations of an organisation that deal directly with the organisation's production activities on which the organisation's fire safety policy must be implemented.

Second, organisations are embedded within a wider socio-economic and physical environment that continuously constrain development. There are various important characteristics or circumstances, such as physical, economic and socio-political characteristics, to which an organisational response is necessary. It seems, however, that the HS(G)65 does not provide an adequate structural organisation that can help not only to give coherence to the HS(G)65 key functions, but also to understand the interaction between the organisation and its environment. Moreover, the HS(G)65 seems to lack an effective structure that may help organisations to structure decision making and communication, and instil their safety culture. The FSMS model discussed above is intended to help an organisation to manage fire safety in a coherent way. The various operations that form part of system 1 can be treated as both vertically and horizontally interdependent. The notion of recursion of the VSM enables the FSMS to deal with vertical interdependence. This means that the organisational structure of the FSMS for the organisation as a whole is replicated in each operation of system 1. The FSMS model is intended to manage fire safety at three levels of recursion and at each level of recursion the FSMS aims to maintain an acceptable level of fire safety, and to favour autonomy and local decision making. The various operations of system 1 are horizontally interrelated as shown in Figure 5.3 of chapter five. These operations are integrated and guided by systems 2 to 5. The interrelationship amongst the operations of system 1 may be strong or weak. However, the operations of system 1 should be given as much autonomy as possible to achieve fire safety policies more effectively. Systems 2 to 5 will intervene in system 1 operations only to ensure the achievement of the organisation's fire safety policies. Apart from the vertical and horizontal interdependence aspects, the structural organisation of the FSMS interacts in a defined way with its wider and local socio-economic and physical environment. This may enable an organisation to adapt continuously according to its weaknesses and strengths, and threats and opportunities as presented in its local and wider environment.

The last point to emphasise is that the measuring and reviewing performance function of the HS(G)65 has some similarities with the communication and control aspects of the FSMS model. However, it should be stressed that the lines that connect the FSMS subsystems and the local and wider environment with the FSMS represent channels of communication, which comply with the four organisational principles of Appendix A. These channels of communication carry fire safety information as plans, reports and special information. These aspects of effective organisation are not dealt explicitly in the HS(G)65, though it suggests some best practices to achieve each function successfully. Additionally, the FSMS suggests a system and a framework called 'fire safety configuration space' that can help when measuring an organisation's fire safety performance. This system consists of four kinds of fire safety levels and these levels can be combined to give four indices expressed in single figures. Moreover, these levels can be used to develop four different fire safety plans. These fire safety levels, plans and indices can be defined for both ICS and ECS for apparent and latent factors.

6.3.2 The "Occupational Health and Safety Management System"

Table 6.2 shows the FSMS model mapped to the "Occupational Health and Safety (OH&S) Management System" based on the BS EN ISO 14001 approach[58]. The OH&S management system elements are associated with the concept of continuous improvement, which involves initial status review, OH&S policy, planning, implementation and operation, checking and corrective action, and management review. Figure 6.2 shows the OH&S Management System.

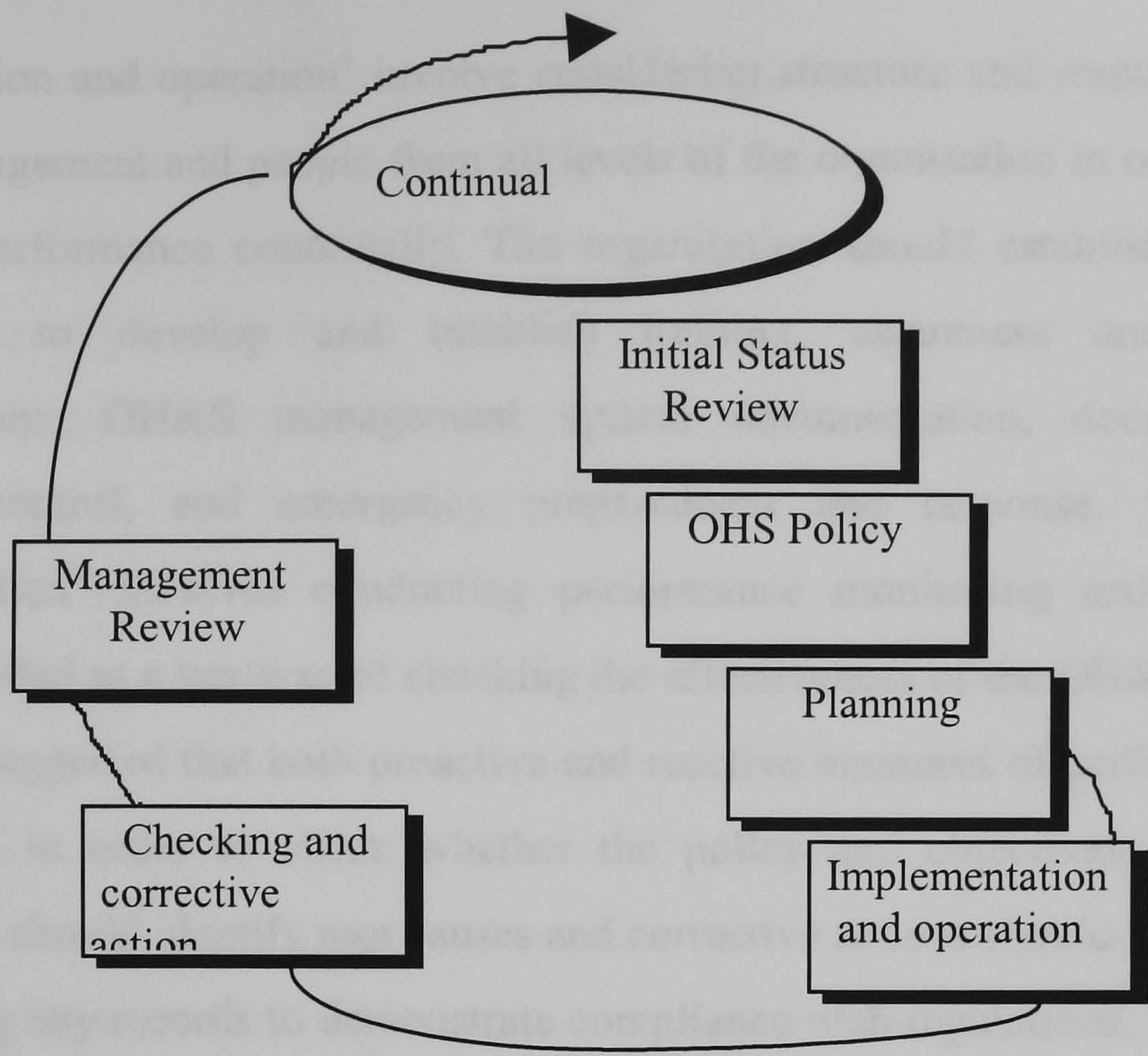


Figure 6.2 The OH&S Management System[58]

Organisations should conduct an 'initial review' of their current safety status to check their existing arrangements with existing regulations, existing OH&S management guidelines, and best practice and performance. This will help them to define the scope, adequacy and implementation of the OH&S management system, as well as measuring progress. The OH&S 'policy' involves documenting and endorsing the organisation's OH&S policy. This policy should reflect a commitment to a number of aspects, such as recognising the OH&S management system as an integral part of the organisation's business, achieving high levels of OH&S performance, allocating resources, setting and publishing OH&S objectives, responsibility of top and line management to managing OH&S, implementing the OH&S policy at all levels, employee involvement and participation, periodic review of the policy, and ensuring that appropriate training is provided for employees at all levels. 'Planning' involves identifying OH&S requirements, setting performance criteria, defining what is to be achieved, delegating responsibilities, defining time scales and setting desired outcomes. The organisation should conduct risk assessment, as well as identifying legal requirements and any other requirements applicable to it. Moreover, the organisation should make arrangements to set overall plans and objectives, develop an understanding of OH&S, set operational plans to implement arrangements, plan for operational control activities, plan for performance measurement, and implement corrective actions.

‘Implementation and operation’ involve considering structure and responsibility of top and line management and people from all levels of the organisation in order to improve the OH&S performance continually. The organisation should establish and maintain arrangements to develop and establish training, awareness and competence, communications, OH&S management system documentation, document control, operational control, and emergency preparedness and response. ‘Checking and corrective action’ involves conducting performance monitoring and measurement, which is regarded as a key way of checking the effectiveness of the OH&S management system. It is suggested that both proactive and reactive measures of performance should be conducted in order to check whether the policy and objectives are being met. Organisations should identify root causes and corrective actions should be taken, as well as maintaining any records to demonstrate compliance with regulations. Besides routine monitoring, periodic audits that enable a critical assessment of all elements of the OH&S management system should be carried out. Finally, organisations should define the frequency and scope of ‘reviews’ of their OH&S management system. The management review should consider the overall performance and the performance of the individual elements of the OH&S management system. It should also consider the results of audits and internal and external factors, such as changes in organisational structure, new regulations and technology. The OH&S management system should be designed to accommodate or adapt to internal and external factors.

The mapping, as given in table 6.2, shows that the OH&S management system has some parallel elements with the FSMS model subsystems. Nevertheless, the functions of the FSMS subsystems are fundamentally different. Furthermore, the OH&S management system does not achieve explicitly the functions of system 4*, system 2 and system 1.

Table 6.2 The FSMS Model and the OH&S Management System

The FSMS Model	The OH&S Management System[58]
• system 5: fire safety policy	• OHS policy
• system 4: fire safety development	• Planning
• system 4*: fire safety confidential reporting	
• system 3: fire safety functional	• implementation and operation
• system 3*: fire safety audit	• checking and corrective action
• system 2: fire safety co-ordination	
• system 1: fire safety policy implementation	
• recursive structure and its environment	
• communication and control	• initial state review and management review

The OH&S management system does not have either an appropriate structure that can help an organisation not only to accommodate the needs presented in its environment, but also to instil its safety culture, to have an effective communication and decision making in a coherent way. The OH&S management system guidelines emphasise that the OH&S management system should be designed to adapt to internal and external needs. But it is not clear how this can be achieved without an appropriate structural organisation. The OH&S management system also lacks an appropriate communication and decision-making model, though it suggests a review of the OH&S management system and the performance of its elements in a defined period. The FSMS model, on the other hand, is a systemic approach that has five necessary and sufficient interrelated subsystems, and that aims to maintain fire risk within an acceptable range throughout an organisation's life cycle. The FSMS has a structural organisation that interacts in a defined way with its local and wider socio-economic and physical environment. This structural organisation helps to adapt continuously to foreseen and unforeseen threats and opportunities, and weaknesses and strengths as presented in the organisation's local and wider environment. Moreover, the structural organisation of the FSMS is intended to manage fire safety in a coherent way by treating an organisation as both vertically and horizontally interdependent. Vertical interdependence deals with the recursive structural organisation of the FSMS. This favours autonomy, so it helps to maintain an acceptable level of fire safety at each level of recursion. The horizontal interdependence deals with the interrelationships amongst the various operations that form part of system 1. The channels that connect the different subsystems of the FSMS are channels of communication and control. These channels should be designed to comply with the four principles of organisation. Additionally, the FSMS suggests a system for measuring the organisation's fire safety performance continuously. The structural organisation, which consists of the five subsystems and the lines that connect them, of the FSMS, its environment, and its channels of communication and control make the FSMS an effective system to manage not only fire safety, but also safety, health and the environment.

6.3.3 The Management System of the European Process Safety Centre

The European Process Safety Centre (EPSC)[116] has developed SMS guidelines. The key elements of the EPSC can be distinguished as policy, organisation, management practices and procedures, monitoring and auditing, and management review, as shown in Figure 6.3.

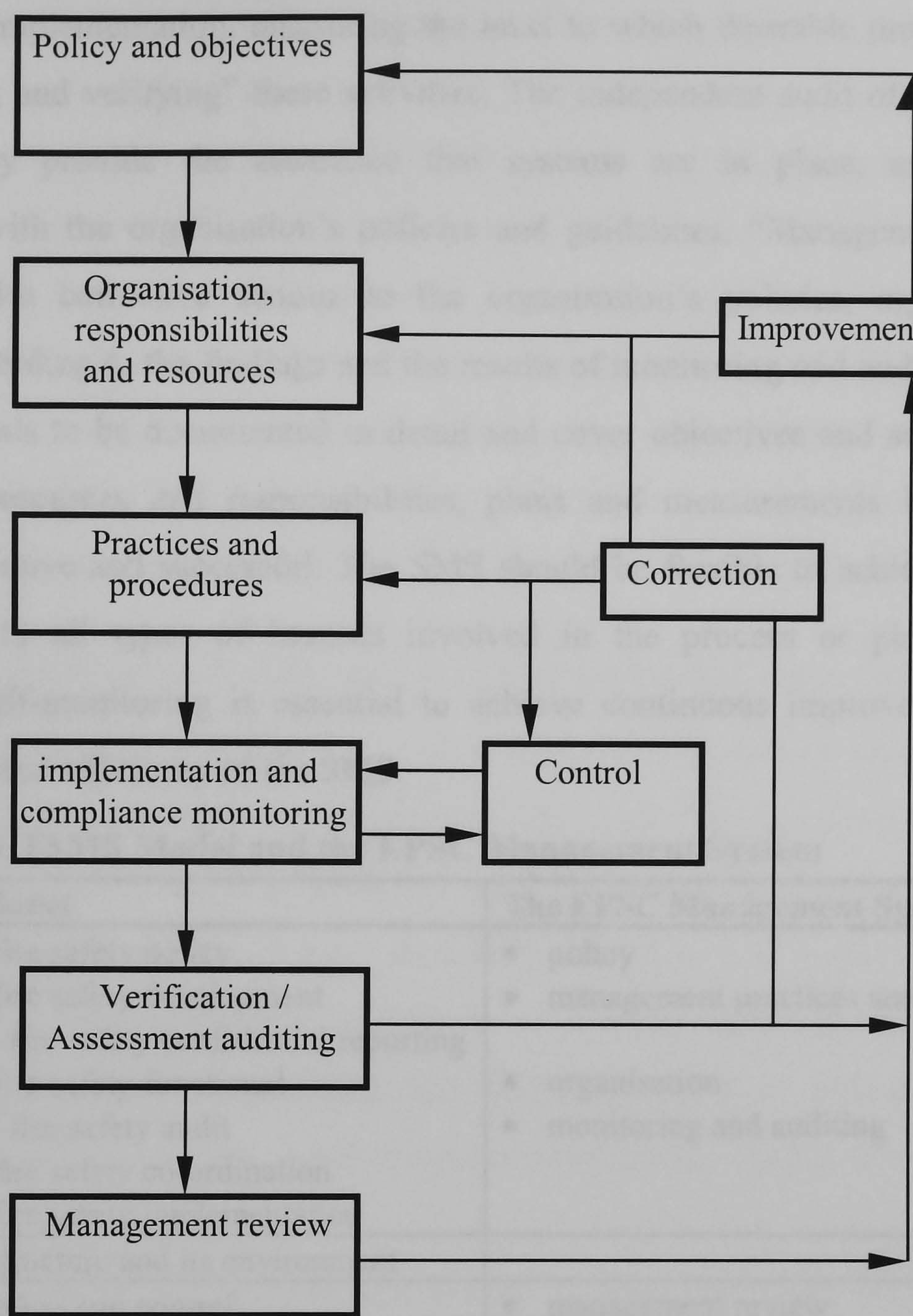


Figure 6.3 The EPSC Management System[116]

An organisation should have a clear and meaningful statement of its safety policy, which reflects the organisation's safety culture, including the ultimate goal of 'zero' accidents and safety objectives as established by the public authorities. "Organisation" involves establishing adequate organisation, assigning responsibilities, and allocating sufficient resources to implement the organisation's safety policy. "Management practices and procedures" are concerned with practices that cover the operations of a facility's life cycle, including inception, planning, hazard identification, assessment and controls, construction, operations, maintenance and repairs, abandonment and disposal. They also include change management, organisational change, reporting, investigation and follow-up of accidents, emergency preparedness, education, training and personnel.

"Monitoring and auditing" involve monitoring the organisation's SMS performance. Monitoring is concerned with measuring the performance of the SMS and the level of SMS policy implementation, measuring the level to which desirable practices are met, and "auditing and verifying" these activities. The independent audit of the monitoring activities may provide the assurance that systems are in place, and checks for compliance with the organisation's policies and guidelines. "Management review" is concerned with corrective actions to the organisation's policies, organisation and resources according to the findings and the results of monitoring and auditing activities. The SMS needs to be documented in detail and cover objectives and scope, tools and procedures, resources and responsibilities, plans and measurements in order to be practical, effective and successful. The SMS should be flexible to achieve widespread applicability to all types of hazards involved in the process or plant. Moreover, continuous self-monitoring is essential to achieve continuous improvement for both effectiveness and efficiency of the SMS.

Table 6.3 The FSMS Model and the EPSC Management System

The FSMS Model	The EPSC Management System[116]
• system 5: fire safety policy • system 4: fire safety development • system 4*: fire safety confidential reporting • system 3: fire safety functional • system 3*: fire safety audit • system 2: fire safety co-ordination • system 1: fire safety implementation	• policy • management practices and procedures • organisation • monitoring and auditing
• recursive structure and its environment	
• communication and control	• management review

Table 6.3 maps the FSMS model to the SMS suggested by the EPSC. This maps shows, first, that some elements of the EPSC are equivalent to some subsystems of the FSMS model. Although these are similar, the functions of the FSMS subsystems are very different from those of the EPSC elements. The EPSC safety management does not explicitly have equivalent functions of system 4*, and system 2 and system 1. Second, the elements of the EPSC management system are arranged in a systematic structure. Moreover, it does not exhibit explicitly the interaction of an organisation with its environment. Finally, the EPSC safety management system does not suggest appropriate communication and control mechanisms, though its management review deals with developing corrective actions according to the monitoring and auditing function.

By contrast, the FSMS model is a systemic approach that has five necessary and sufficient interrelated subsystems, which are arranged in an effective structural organisation that aims to maintain an acceptable level of fire safety in an organisation's operation life cycle. The FSMS addresses fire safety in a coherent way by treating an organisation as both vertically and horizontally interdependent. The vertical interdependence deals with the recursive property of the structural organisation of the FSMS and the horizontal interdependence deals with interrelationships amongst the various operations of system 1. Moreover, this structural organisation interacts with its local and wider environment in a defined way. The FSMS also contains a communication and control model. The structural organisation and the communication and control model are the basic criteria of effectiveness of the FSMS.

6.3.4 Total Oil Marine 'Safety and Environmental Management System'

Table 6.4 maps the FSMS to the Total Oil Marine's (TOM) Safety and Environmental Management System (SEMS). TOM plc is a UK North Sea producer of oil and gas. TOM plc, like many other UK North Sea oil and gas operators, has to comply with safety and environmental regulations, especially the safety case regulations. TOM plc has developed and established a SEMS to comply with existing safety and environmental regulations. Similarly, the SEMS consists of policy, organisation, planning and implementation, performance measurement, performance review, and auditing, as shown in Figure 6.4.

TOM's safety, health and environment policy is concerned with the organisation's commitment in order to "minimise" the safety and health risks to all those in its sites and to reduce the impact of its operations on the environment. This policy influences all areas and activities of the organisation. In the organisation, effective communications and the safety committee structure in place are intended to ensure that all levels of the organisation are involved in decisions to improve its safety or environmental performance. TOM personnel are assigned responsibilities to undertake their work "safely" and to be fully aware of their responsibilities to themselves, to others and to the environment. Through 'planning', TOM eliminates or "minimises" (their word) and controls risks to people, the environment and facilities. Planning is also concerned with setting objectives and monitoring them. Safety meetings, pre-job meetings and handover procedures ensure tasks are sufficiently analysed.

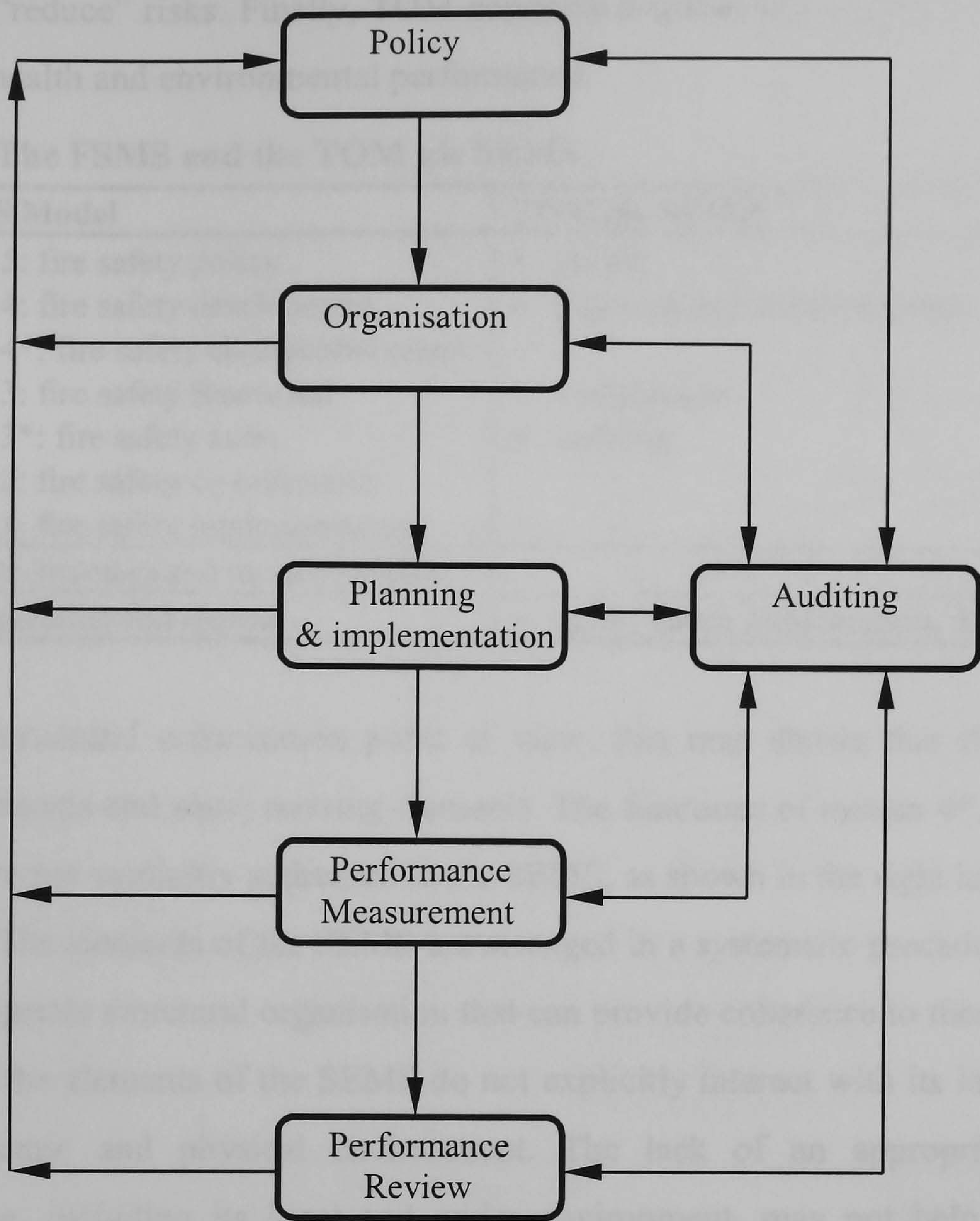


Figure 6.4 TOM plc SEMS[158]

Emergency response procedures and training are in place and regularly tested to be used in the event when prevention fails. TOM conducts "active" and "reactive" performance measurement. "Active performance measurement" involves monitoring its performance against pre-defined standards to identify weaknesses. This monitoring ranges from normal, independent audits to site or module inspections, and individual staff appraisals. "Reactive performance measurement" involves monitoring failures of control through incident reporting and investigation procedures to identify the underlying causes of accidents. According to the results of the performance measurement stage, TOM conducts performance reviews throughout all areas of the company. Action is taken to improve any weaknesses or to prevent incident recurrence. It also regularly 'reviews' its policy, as well as reviewing both company key performance indicators and individual objectives. TOM's safety case is reviewed annually to update. Systems and modifications with high risks are reviewed to update current procedures or designs and to further "reduce" risks. Finally, TOM conducts a systematic audit and monitoring of its safety, health and environmental performance.

Table 6.4 The FSMS and the TOM plc SEMS

The FSMS Model	TOM plc SEMS[158]
• system 5: fire safety policy • system 4: fire safety development • system 4*: fire safety confidential report • system 3: fire safety functional • system 3*: fire safety audit • system 2: fire safety co-ordination • system 1: fire safety implementation	• policy • planning and implementation • organisation • auditing
• recursive structure and its environment	
• communication and control	• performance measurement, & review

From the structural organisation point of view, this map shows that there are some parallel elements and some missing elements. The functions of system 4*, system 2 and system 1 are not explicitly addressed in the SEMS, as shown in the right hand column of Table 6.4. The elements of the SEMS are arranged in a systematic procedure rather than in an appropriate structural organisation that can provide coherence to these elements. It seems that the elements of the SEMS do not explicitly interact with its local and wider socio-economic and physical environment. The lack of an appropriate structural organisation, including its local and wider environment, may not help TOM plc to manage safety, health and the environment effectively. Moreover, this deficiency may not help to implement a communication and decision-making process effectively. By contrast, the FSMS has five necessary and sufficient interrelated subsystems, which are arranged in a recursive structural organisation that are intended to help it to manage fire safety in a coherent way. The structural organisation of the FSMS interacts in a defined way with its local and wider environment. It also contains a communication and control model that is intended to ensure the effectiveness of the FSMS. Moreover, it is believed by the author that the FSMS can help not only to manage fire safety in a coherent way, but also to manage safety, health and the environment and for any organisation.

6.3.5 Conoco UK Ltd (CUKL) 'Safety, Health and Environmental Management System'

Table 6.5 maps the FSMS to the CUKL Safety, Health and Environmental Management System (SHEMS). CUKL is a UK North Sea based producer of oil and gas. The CUKL

SHEMS is based on the "Successful Health and Safety Management" (HS(G)65) format, as shown in Figure 6.5.

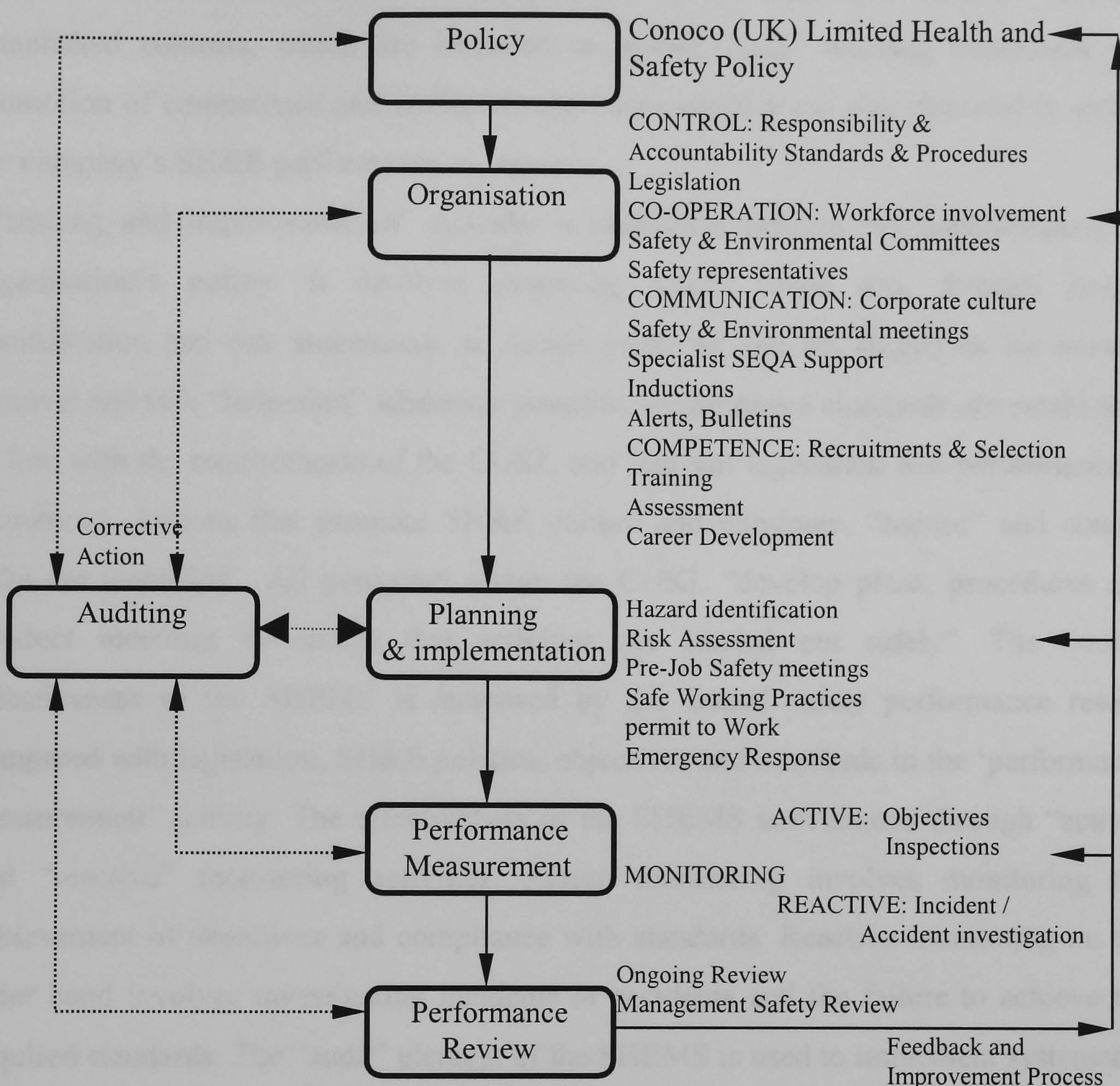


Figure 6.5 CUKL SHEMS[159]

The SHEMS key elements, which are also associated with control loops, include policy, organisation, planning and implementation, performance measurement, performance review, and auditing. "Policy" describes CUKL's intentions and commitment to safety, health and the environment (SH&E), and the established organisational responsibilities and arrangements, which are intended to ensure the successful implementation of the organisation's policies. The SH&E policies, which are a statement of the standards by which CUKL operates, support and contribute to business objectives and state the company's commitment to meet existing regulations. The primary objective of the SHEMS is to implement these policies. "Organisation" describes the organisational structure, roles and responsibilities, accountability and resources, established to ensure the implementation of the HSE policies. CUKL states that it implements its SHE policies through involvement and participation, top and line management commitment, effective communication and the co-operation of its workforce. Besides this, the established controls, which are intended to ensure "safe" working conditions, the promotion of competence and environmental responsibility are also intended to enable the company's SH&E performance to improve.

"Planning and implementation" describe a systematic process for implementing the organisation's policy. It involves preparing safety cases and, through hazard identification and risk assessment, to decide priorities and set objectives for hazards removal and risk "reduction" whenever possible. Performance standards are established in line with the requirements of the CUKL and relevant legislation and performance is monitored. Actions that promote SH&E culture and eliminate, "reduce" and control risks are identified. All personnel within the CUKL "develop plans, procedures and conduct meetings to ensure that activities are carried out safely". The overall effectiveness of the SHEMS is measured by the annual safety performance results compared with legislation, SH&E policies, objectives and standards in the 'performance measurement' activity. The effectiveness of the SHEMS is evaluated through "active" and "reactive" monitoring activities. Active monitoring involves monitoring the achievement of objectives and compliance with standards. Reactive monitoring on the other hand involves investigating incidents or accidents and the failure to achieve the required standards. The "audit" element of the SHEMS is used to implement systematic, independent, and cross-functional audits to determine the effectiveness of the SHEMS and identify opportunities for improvement. SHEMS audits are carried out annually on CUKL production locations to identify corrective actions raised from previous audits or the annual management safety and environmental review, or as a result of any changes implemented in the organisation. The review of performance against agreed goals and objectives and standards takes place at varying intervals. CUKL reviews annually the SHEMS to ensure that its policies are being implemented and to assess the adequacy of the audit programme in place. The review includes "making value judgements about performance and initiating actions for improvements."

Table 6.5 The FSMS Model and the CUKL SHEMS

The FSMS Model	CUKL SHEMS[159]
• system 5: fire safety policy • system 4: fire safety development • system 4*: fire safety confidential report • system 3: fire safety functional • system 3*: fire safety audit • system 2: fire safety co-ordination • system 1: fire safety implementation	• policy • planning and implementation • organisation • audit
• recursive structure and its environment	
• communication and control	• measuring and reviewing performance

The mapping in table 6.5 shows some missing elements. The functions of system 4*, system 2 and system 1 are not explicitly listed in the right hand column of Table 6.5. This mapping also shows some parallel elements between the FSMS and the SHEMS. The SHEMS itself lacks an appropriate organisational structure that can help CUKL to manage SH&E in a coherent way. The traditional hierarchical organisational structure is described in the organising element of the SHEMS. Moreover, the organisational structure described in the organising element of the SHEMS does not include the interaction of CUKL with its local and wider socio-economic and physical environment. Hence, this deficiency militates against the implementation of an effective communication and decision making process. The primary objective of the SHEMS is "the implementation of the HS&E policies". By contrast, the FSMS is intended to help an organisation to maintain risk within an acceptable range throughout the life cycle of the organisation's operations. The FSMS has five necessary and sufficient interrelated subsystems, which are arranged in a recursive structural organisation that interacts in a defined way with an organisation's local and wider environment. Besides this, the FSMS also contains a communication and control model that ensures the effectiveness of the FSMS in achieving its purpose. It is hoped that the FSMS can help not only to manage fire safety more effectively, but also to manage safety, health and the environment and for any organisation.

6.4 Conclusion

This chapter has discussed a limited evaluation process for the FSMS model. It started by presenting some problematic aspects that were found during the evaluation process of the FSMS model. The chapter continued by discussing the results of the assessment of some existing SMSs.

Chapter Seven

Case Study: An Assessment of Britain's Railway Safety Management

7.1 Introduction

Chapter six presented the evaluation process of the FSMS model. The researcher used this model to assess the safety management of Britain's railway. This chapter gives an account of this case study. Section 7.2 describes the safety management in the railway industry as it is currently practised. The commercial aspects of the railway industry and its safety considerations are treated in section 7.3. A systemic Railway Safety Management System is presented in section 7.4. Finally, some conclusions are given in section 7.5.

7.2 Safety Management in the Railway Industry

The British railway industry is a complex organisation that has various parts whose business activities deal with hazards. These hazards have the potential to create significant risks not only for the passengers, employees, contractors and the public, but also for the natural environment. Recent train accidents, such as the Paddington rail crash and the Hatfield train derailment, have highlighted this potential. It seems, therefore, that the current safety management of the railway industry is not sufficient to cope with the changing nature of the relationships amongst the various operating companies that form the railway industry. Prompted by the railway accidents, this case study is intended to highlight some weaknesses of the SMS of the railway industry. It also suggests a systemic approach that could be adopted by the railway industry, which it is believed, will contribute to improve railway safety.

There are five key and independent organisations in the British rail system[160]. These organisations are Railtrack plc, train and freight operating companies, rolling stock companies or vehicle owners, contractors, and regulators. As shown in Figure 7.1, Railtrack plc is a subsidiary of Railtrack group plc; Railtrack group plc sets out the Railtrack plc Safety Case. On the other hand, Railtrack owns and controls the majority of the rail infrastructure; that is, the track, signals, bridges, viaducts, tunnels, level crossings, major stations and so on. Contractors deal with the maintenance and renewal of the rail infrastructure; that is, they work for Railtrack plc. The train operating companies (TOCs) and freight operating companies (FOCs) operate the trains and in many cases the stations. The rolling stock companies (ROSCOs) or vehicle owners lease rail vehicles to TOCs.

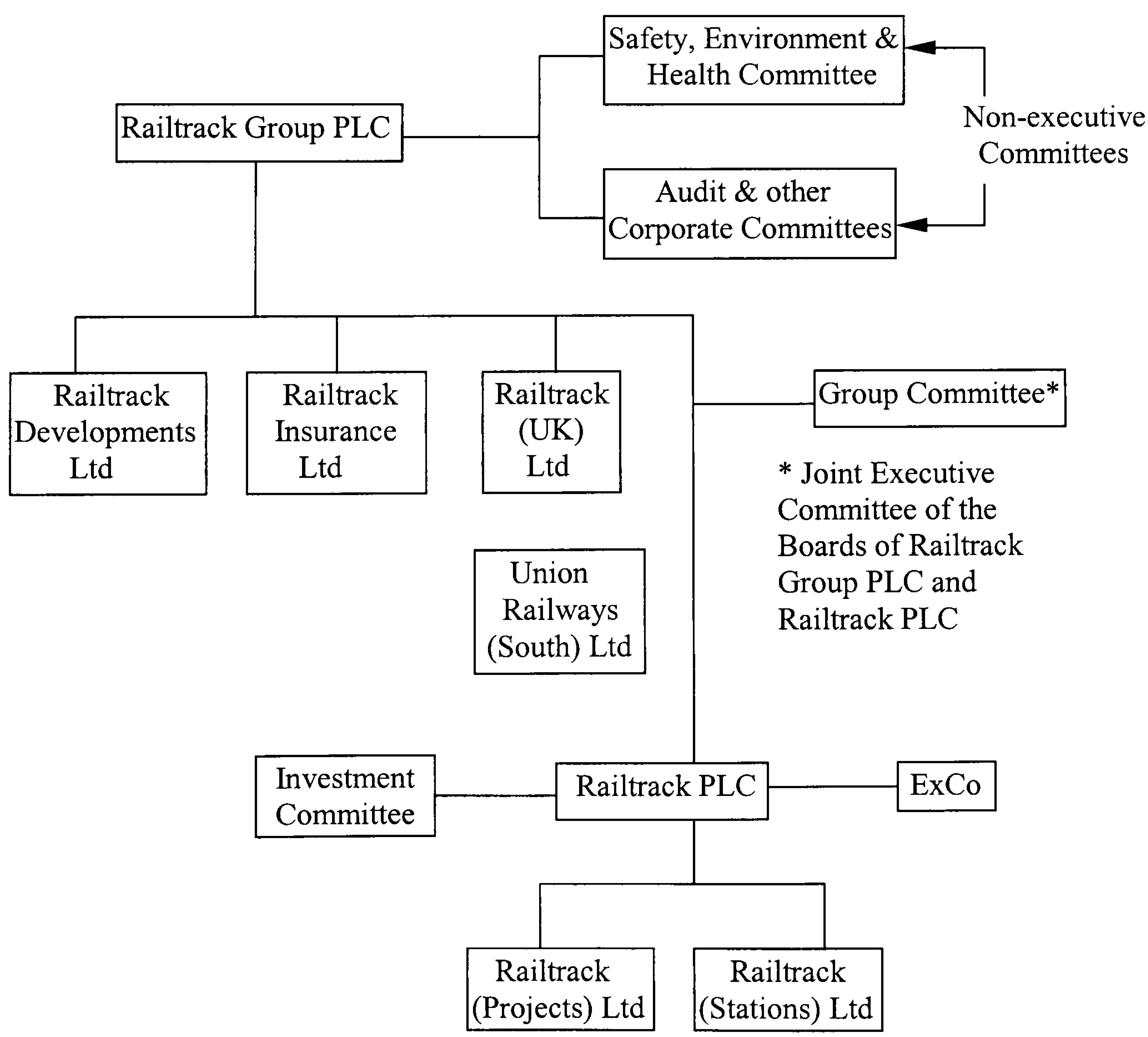


Figure 7.1 Railtrack Corporate Structure[160]

Under the Railway (Safety Case) Regulations[161] (RSC), Railtrack plc is the main controller of the rail infrastructure; its responsibility is to provide a RSC to HSE and to accept the Safety Case of TOCs and station operators. The role of the Group committee, which is an executive committee of Railtrack Group and Railtrack, is to deal with the day-to-day business, as well as to address safety, environment and health. The Executive Committee (ExCo) is a group formed by the Railtrack plc chief executive and Zone Directors and other key operational personnel whose responsibilities are to establish the means to meet business and operational safety objectives.

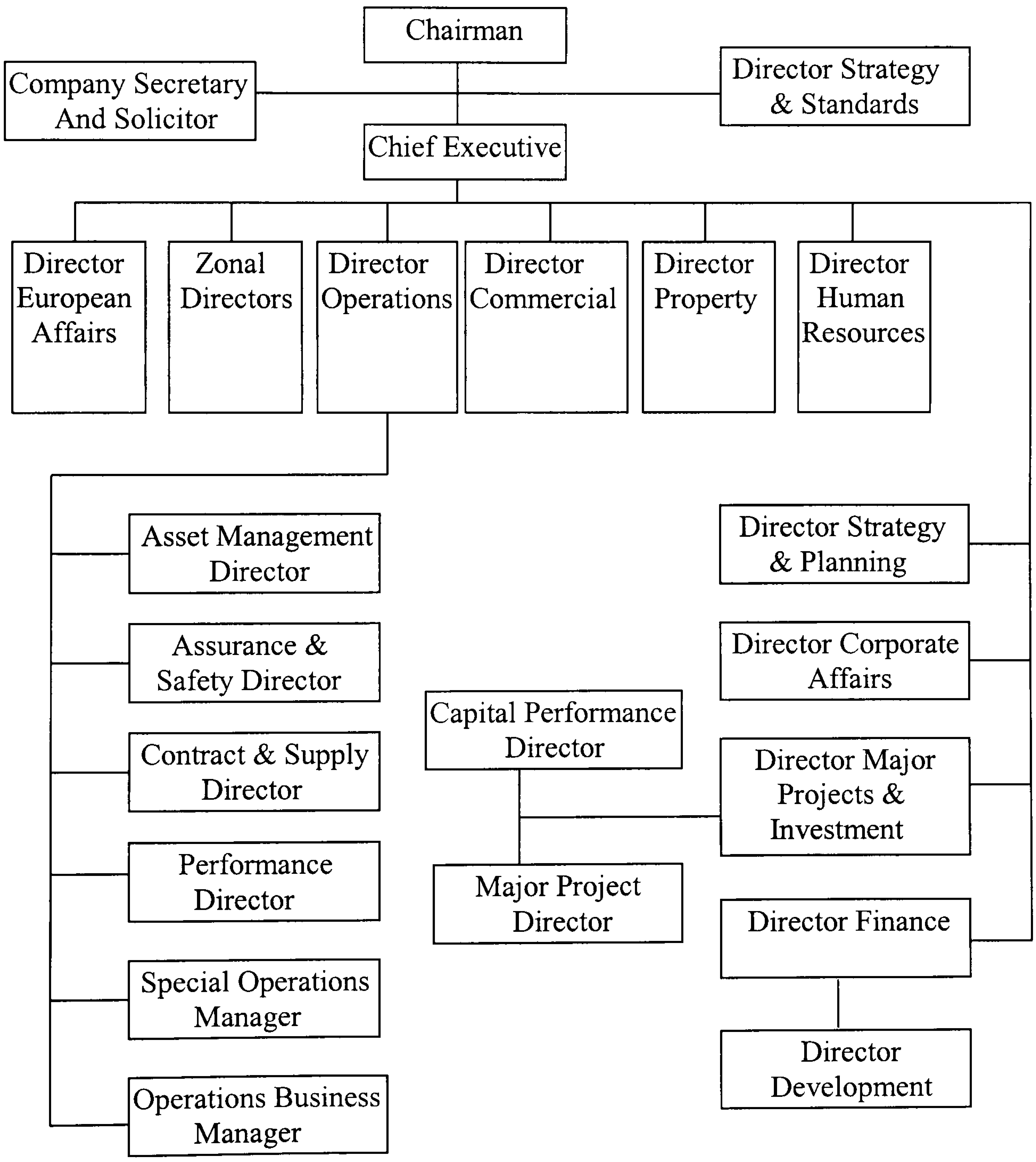


Figure 7.2 Railtrack plc Line Structure[160]

Figure 7.2 shows the structure of the Railtrack line. Through its head-quarter functions and seven zones, it deals with commercial and operational activities to maintain and develop the railway infrastructure. Railtrack has a commercial relationship with the TOCs, FOCs and station operating companies; Railtrack claims that it accepts and monitors TOCs (including FOCs) RSCs. This has the potential to create conflicting interests between business and safety issues. Safety is therefore considered as an integral function within the line management functions. However, there are some independent functions, such as the Assurance and Safety Directorate (A&SD) and the Safety and Standards Directorate (S&SD) that deals directly with safety issues. The A&SD deals with the Railtrack line safety and reports to the Operations Director. The S&SD deals exclusively with safety and provides service to the Railtrack line through providing advice, auditing and preparing the RSC.

The primary railway regulation is contained in the Health and Safety at Work etc. Act 1974. This regulation requires the railway industry to conduct undertakings in such a way so as to ensure, so far as is reasonably practicable, that their employees and any others who may be affected are not exposed to risks to their health and safety. The Management of Health and Safety at Work Regulations 1992, which require, amongst other things, risk assessments to be undertaken, are also relevant to the railway industry. Besides these general laws, there are some specific regulations for the railway industry such as the RSC Regulation 1994. The RSC requires Railtrack, train or station operating companies to produce their Safety Case to demonstrate their safety policy, risk assessment, SMS, operational, maintenance and audit arrangements. HSE assesses and accepts the Safety Case of Railtrack plc, whilst the Safety Cases of the train and station operating companies are assessed and accepted by Railtrack plc. However, the new RSC regulations 2000[162] require TOCs, FOCs and station operating companies to pass their RSCs from Railtrack to the HSE. RSCs are reviewed, at least every three years, whenever appropriate by the operators. In addition to the RSCs there are other Regulations dealing with competence of employees performing safety critical functions; approvals by HSE for new engineering works undertaken by, or on behalf of, Railtrack; approvals by HSE for new traction and rolling stock; future prohibitions on train operating without train protection systems, or with certain types of rolling stock; and miscellaneous provisions dealing with access to the infrastructure, passenger communication, preventing collisions and derailments, providing and maintaining brakes, and accidents to people at work from moving vehicles. The Office of the Rail

Regulator (ORR), the Office of Passenger Rail Franchising (OPRAF), and the Shadow Strategic Rail Authority (sSRA) have also an influence on Railtrack operations. The ORR grants a licence only with a condition that the operator has an accepted RSC. The OPRAF monitors and manages the passenger train franchises operating in the UK in order to promote the interests of passengers through improved quality of service. The sSRA will, *inter alia*, subsume the functions of OPRAF and the ORR.

It is claimed by the HSE[160] that it undertakes reviews of management arrangements for health and safety within large organisations. The mission of HSE is to ensure that risks to people's health and safety from work activities are properly controlled[161].

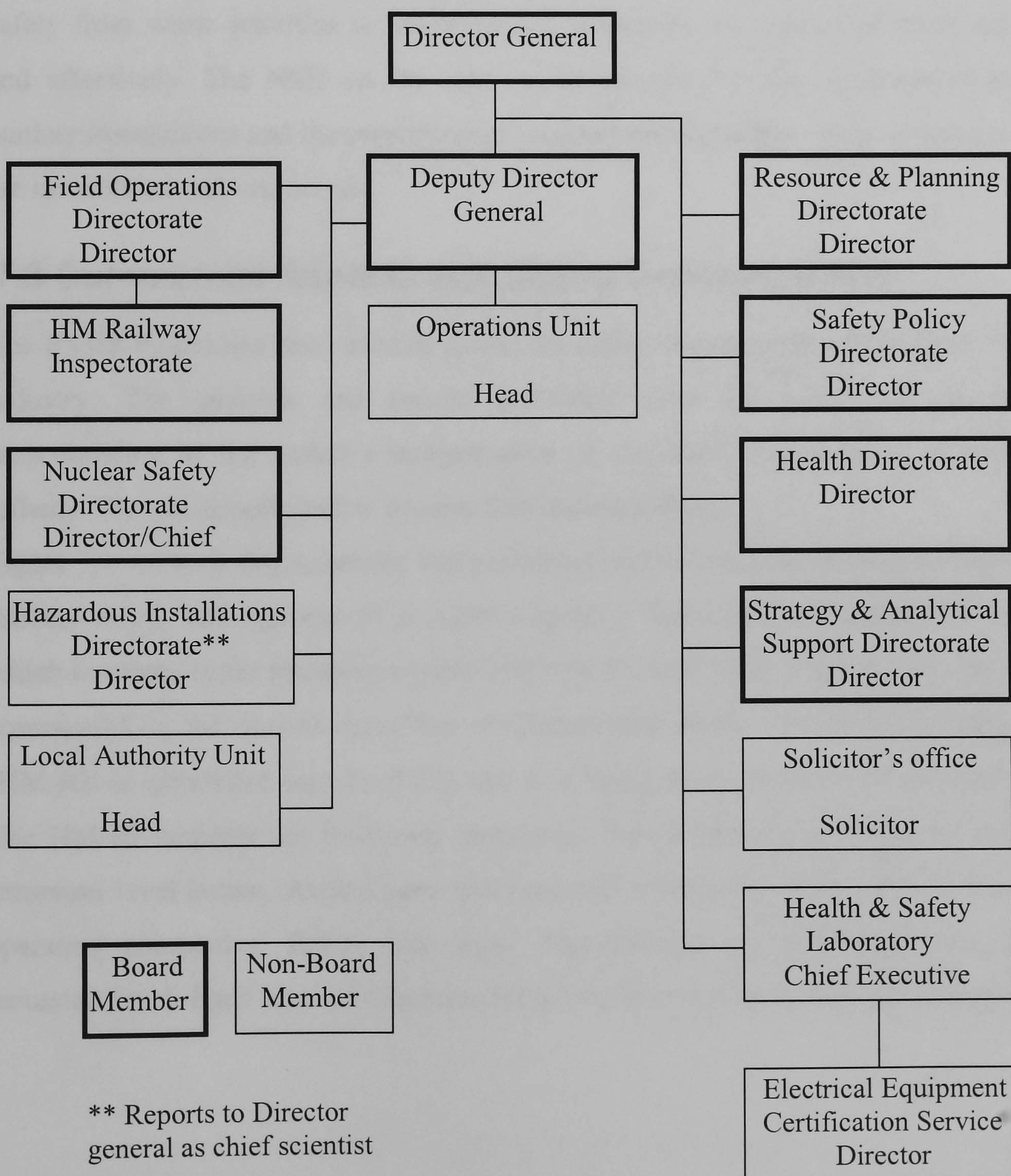


Figure 7.3 The Health and Safety Executive (HSE)[160]

Figure 7.3 shows the Divisions and Directorates that form the HSE. Three Directorates are of great interest here in order to manage safety in the Railway industry. They are the Field Operations Directorate (FOD), Hazardous Installations Directorate (HID) and Nuclear Safety Directorate (NSD). The FOD addresses many industrial sectors, which include HM Railway Inspectorate, construction, agriculture, manufacturing and so on. It inspects workplaces and investigates accidents and compliance, as well as providing advice and guidance on how to comply with the law. The function of HM Railway Inspectorate in particular is to ensure that risks to the health and safety of employees, passengers and others who might be affected by the Railway industry activities are "properly controlled". The HID's role is to ensure that risks to people's health and safety from work activities in major hazard industries are controlled more efficiently and effectively. The NSD on the other hand ensures that the standards of safety at nuclear installations and the protection of workers and the public from ionising radiation are maintained and improved.

7.3 Commercial Aspects and Safety Considerations

The FSMS model has been used to assess the safety management of the British railway industry. The analysis and results presented here are based on the previous understanding of the author's interpretation of the safety management of the British railway. The paragraphs below present this understanding.

Figure 7.4 shows a diagrammatic representation of five levels of recursion of the British railway safety management as it exists currently. Recursion one represents the HSE, which has three main operations named FOD, HID, and NSD. The FOD in turn is being represented in the second recursion. As mentioned above, HM-Railway Inspectorate (HM-RI) is embedded into the FOD and it is being represented in the recursion three. The HM-RI inspects the Railtrack operations; thus Railtrack is located in the fourth recursion level below. As Railtrack assesses and accepts the TOCs, FOCs, and station operating companies' RSCs, then these organisations are embedded into the fifth recursion level. Each level of recursion has a connection with its local environment.

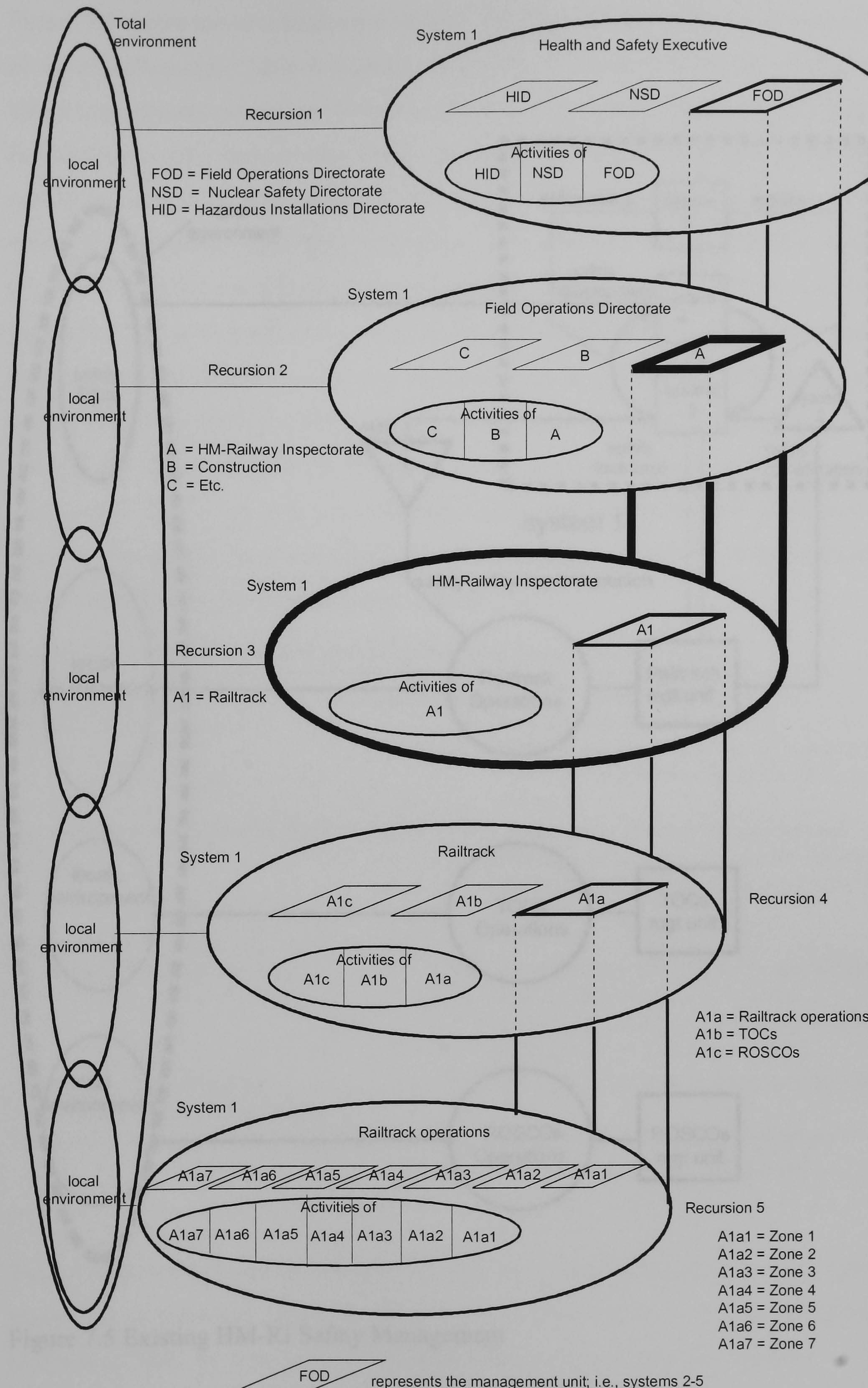


Figure 7.4 HM-RI Recursive Structure

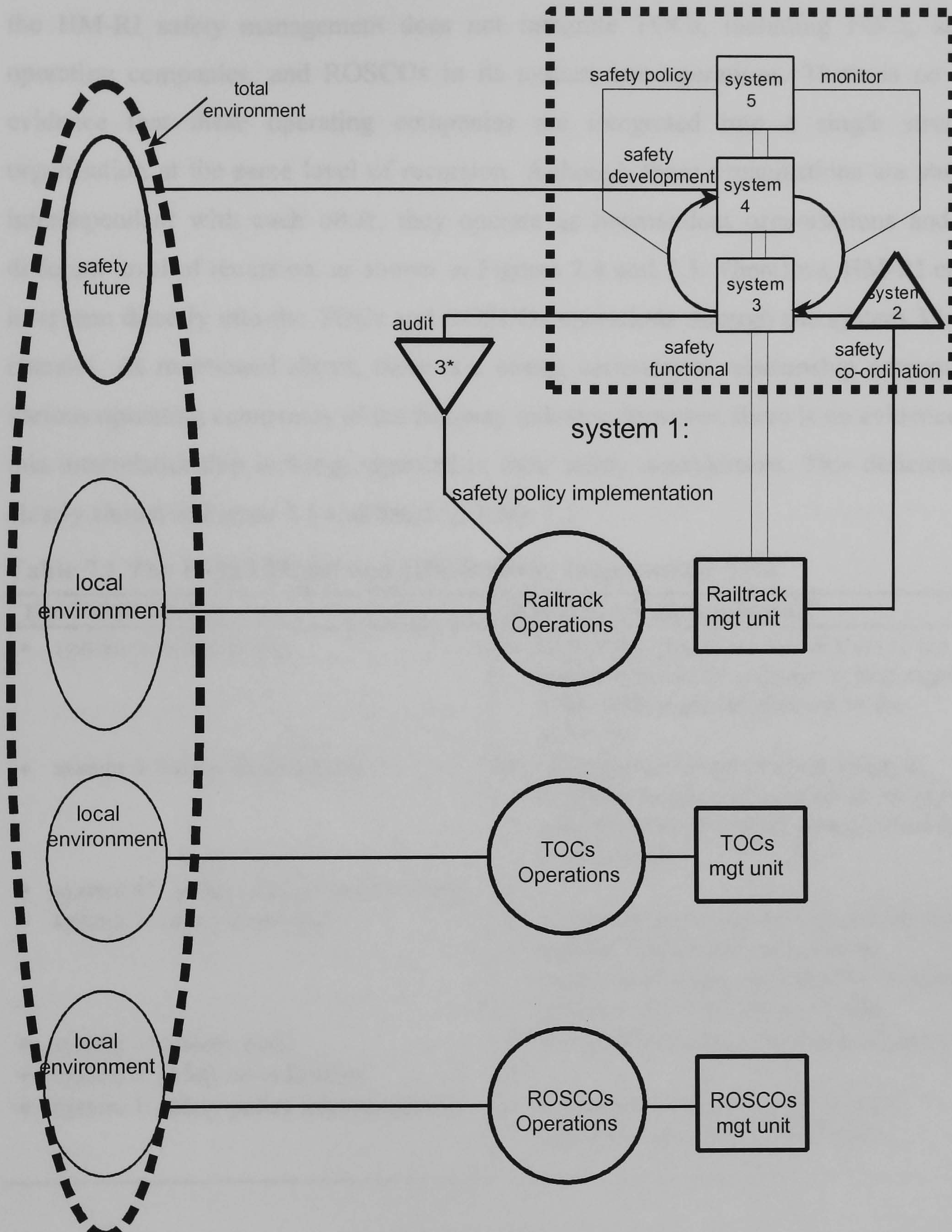


Figure 7.5 Existing HM-RI Safety Management

Figure 7.5 shows the structural organisation of the HM-RI, recursion three, in the format of the FSMS model. Table 6.6 summarises some relevant deficiencies of the HM-RI safety management according to Figure 7.5. As can be seen in Figure 7.5 and Table 6.6, the HM-RI safety management does not integrate TOCs, including FOCs, station operating companies, and ROSCOs in its system one operations. There is no clear evidence that these operating companies are integrated into a single structural organisation at the same level of recursion. Although these organisations are strongly interdependent with each other, they operate as independent organisations and at a different level of recursion, as shown in Figures 7.4 and 7.5. Therefore, HM-RI cannot intervene directly into the TOCs and ROSCOs operations through the system 3* audit channel. As mentioned above, there is a strong commercial relationship amongst the various operating companies of the Railway industry; however, there is no evidence that this interrelationship is being regarded in their safety management. This deficiency is clearly shown in Figure 7.5 and listed in Table 7.1.

Table 7.1 The FSMS Model and HM-Railway Inspectorate SMS

The FSMS Model	HM-Railway Inspectorate[160]
• system 5: safety policy	• Secure the proper control of risks to the health & safety of employees, passengers & others that might be affected by the railways.
• system 4: safety development	• Investigation of accidents & monitor accidents trends, influencing the industry and others on all aspects of regulation & management.
• system 4*: safety confidential reporting	•
• system 3: safety functional	• Inspect & approve proposals new or altered railway "hardware" (new works, equipment, rolling stock & level crossings), guidance & advice of new works.
• system 3*: safety audit	• No audit on railway operating companies
• system 2: safety co-ordination	•
• system 1: safety policy implementation	• no interaction amongst the railway operating companies & Railtrack

The co-ordination function amongst the Railway safety management does not exist, though in commercial terms all operating companies agree on train planning and timetables. Due to this lack of understanding of co-ordination function of safety management, the safety of the organisation as a whole can be seriously compromised. The Paddington train crash[163] of 5 October 1999, when 31 people die and 245 were injured, and the Hatfield train derailment[164] on 17 October 2000, to mention two, are examples of the consequences of the lack of co-ordination function. Unless this key co-ordination and other organisational functions are considered, train incidents and accidents will continue to happen. Therefore, there is a need for an approach that could help to integrate the railway operating companies into a coherent whole so that safety can be managed more effectively. Moreover, the HM-RI has no function that deals with confidential reports. The confidential reporting function can be achieved through system 4* of the FSMS model. System 4* is concerned with confidential reports, received from system 1, 2 and 3, that may require direct intervention of system 5.

It seems that the HM-RI SMS does not provide an adequate structural organisation that can help not only to give coherence to the railway operating companies, but also to understand the interaction between these companies and their environment. Moreover, the HM-RI SMS has a very poor communication system and safety culture due to the lack of an effective structural organisation. For example, Railtrack does not know the safety performance of its commercial partners, such as the TOCs; the opposite is also true. The railway operating companies' safety performance is an issue for the S&SD rather than sharing safety information amongst them. The most relevant deficiency of HM-RI SMS is the lack of an organisational structure that can help to manage safety in a coherent way; that is, concerning horizontal and vertical interdependence, as well as to structuring decision making, communication systems and inculcating the railway safety culture.

It must be realised, though, that even if more vertical links were in place on Figure 7.5, appropriate action would not necessarily be guaranteed. For example, even if there were vertical links between "Railtrack operations" and "ROSCOs operations" in Figure 7.5, suitable action might be deferred in a given case because of commercial interests. A specific case might be a lack of incentive for the ROSCOs to conduct "wheel turning" on their rolling stock because of commercial interests and the fact that they do not have a responsibility to maintaining the track. ("Wheel turning" refers to periodically grinding wheel surfaces to smooth them and reduce wear on the track).

Regarding commercial aspects, the various railway operating companies are grouped according to Figure 7.6. Railtrack plc serves TOCS and FOCs. As can be seen in Figure 7.6, there is co-ordination between these two operations of system 1. It is in this function where the access to the rail network, allocation of train paths, planning and co-ordination of train movements, and production of timetables takes place. It can be seen also that TOCs have strong relationship with ROSCOs who owns the train vehicles.

This close co-operation is achieved through the co-ordination function of system 2. It should be emphasised that safety is not embedded into this commercial management system, though Railtrack[160] claims that there is "no evidence of commercial interests outweighing safety considerations". A clear evidence of the split between commercial considerations and safety is that the S&SD became a separate unit within Railtrack on 1 April 2000. The S&SD is the organisation that assesses the TOCs' Safety Cases and audits the operations of Railtrack plc and TOCs. According to the information available to the researcher, it is not clear how the audit channel is used to intervene in the operations of the key players of the railway industry. It should be emphasised that the arrangement shown in Figure 7.6 is the same as Figure 7.5, but the railway commercial management has a co-ordination function. Commercial requirements are all profit and customer service with no embodiment of safety. This is the pattern imposed by Government and used as safety management because there is no pressure and drive to be different.

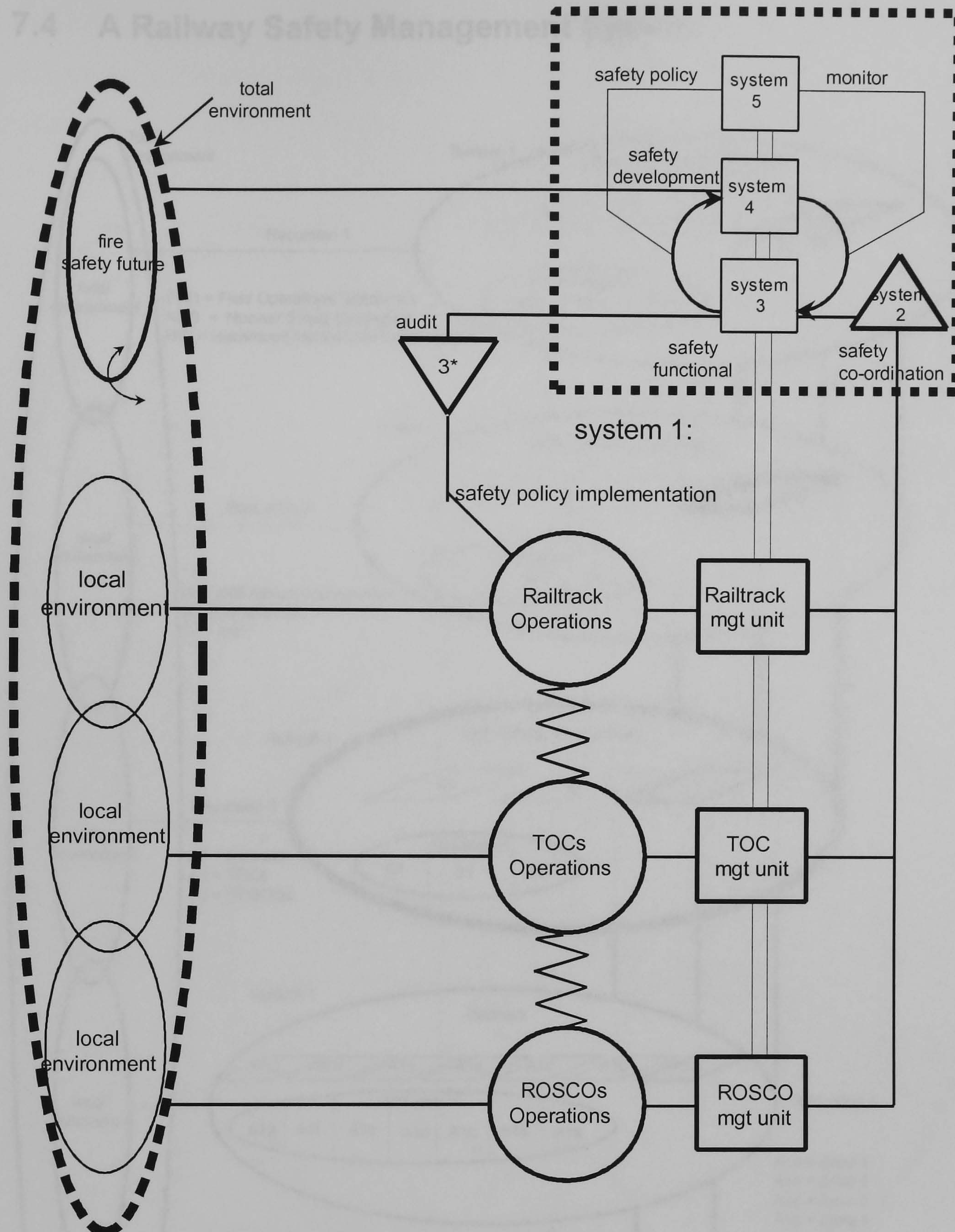


Figure 7.6 Railway Industry Commercial Management System

7.4 A Railway Safety Management System

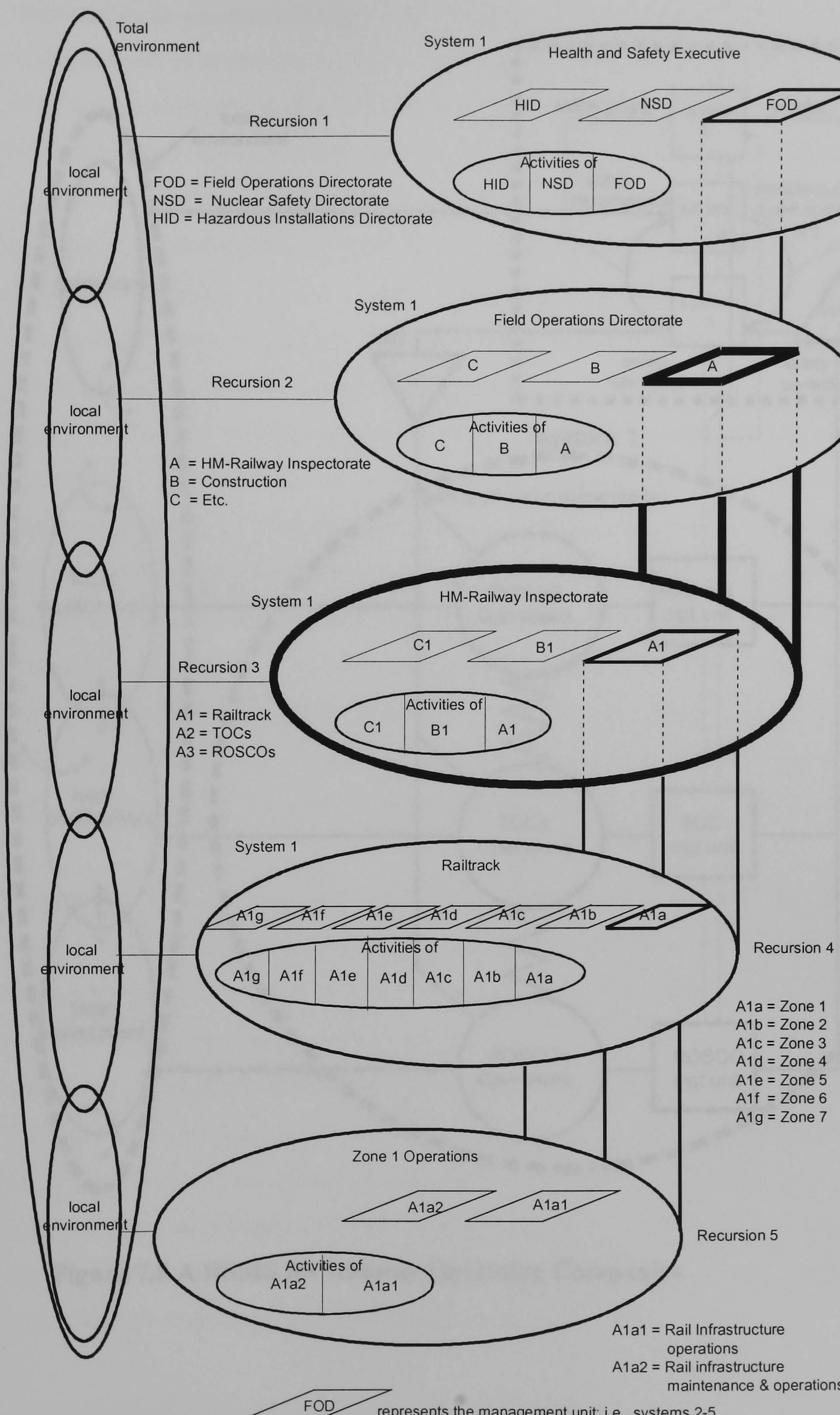


Figure 7.7 Levels of Recursion of the British Railway Industry

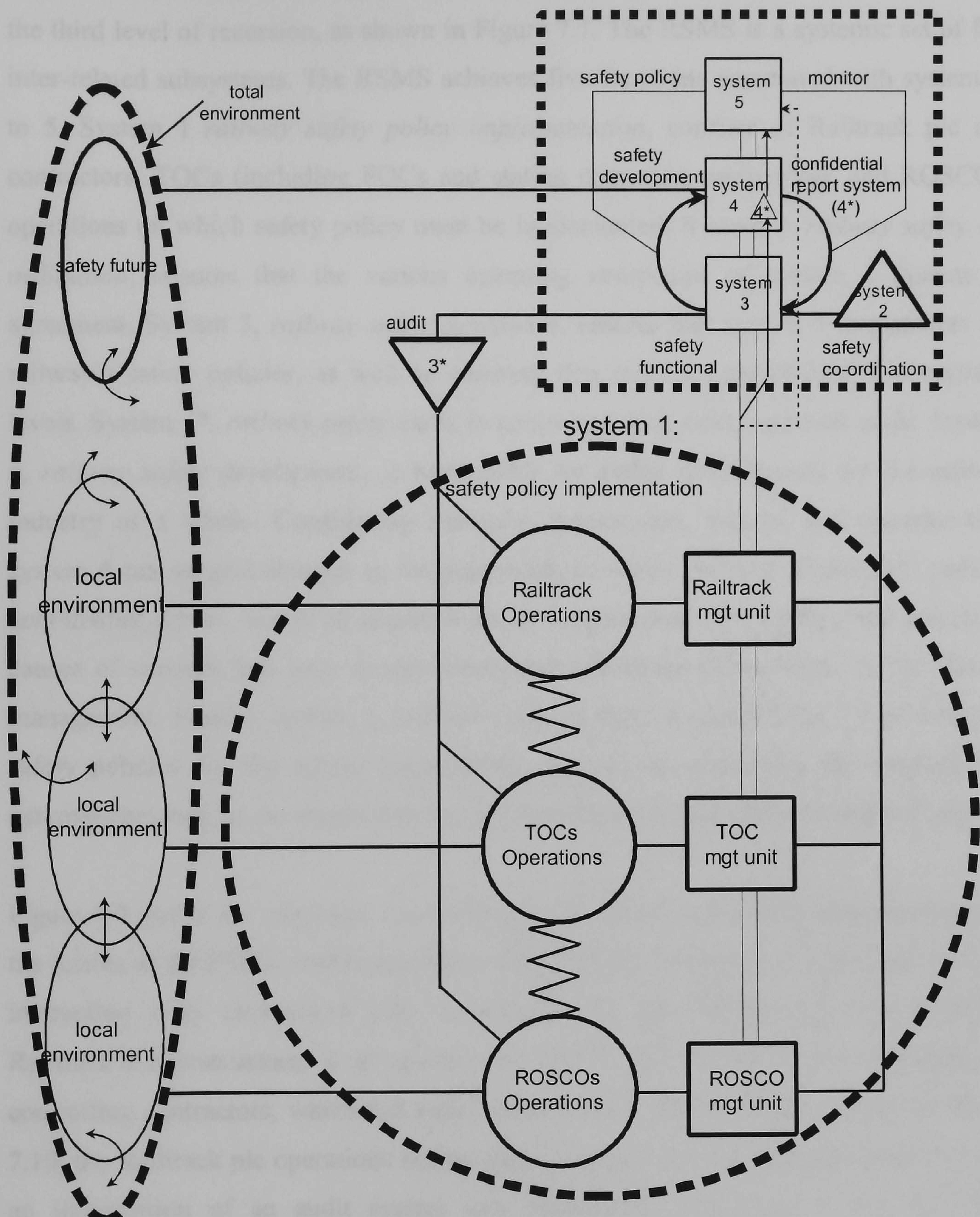


Figure 7.8 A RSMS for Railway Operating Companies

Figure 7.7 shows five possible levels of recursion of the British railway industry. Figure 7.8 shows a Railway Safety management System (RSMS) that may help to maintain risks within an acceptable range in the Railway industry. The RSMS was modelled for the third level of recursion, as shown in Figure 7.7. The RSMS is a systemic set of five inter-related subsystems. The RSMS achieves five functions associated with systems 1 to 5. System 1 *railway safety policy implementation*, consists of Railtrack plc and contractors, TOCs (including FOCs and station operating companies), and ROSCOs' operations on which safety policy must be implemented. System 2, *railway safety co-ordination*, ensures that the various operating companies of system 1 operate in agreement. System 3, *railway safety functional*, ensures that system 1 implements the railway's safety policies, as well as ensuring that risks are maintained at acceptable levels. System 3*, *railway safety audit*, is concerned with safety sporadic audit. System 4, *railway safety development*, is responsible for safety development for the railway industry as a whole. Considering strengths, weaknesses, threats, and opportunities, system 4 can suggest changes to the organisation's safety policies. System 4*, *railway confidential report*, is part of system 4 and it is concerned with confidential reports or causes of concern that may require direct and immediate intervention of the HM-RI management. Finally, system 5, *railway safety policy*, is responsible for establishing safety policies for the whole organisation, as well as monitoring the internal and external demands, as represented by the needs of system 3 and system 4 respectively.

Figure 7.9 shows the structural organisation of Railtrack at the fifth recursion level in the format of the FSMS model. Similarly, the Railtrack operations at zone level have no interaction with contractors who are responsible for maintaining and renewing Railtrack's infrastructure. It is reported by HSE[160] that Railtrack plc has problems controlling contractors, which has safety implications. This is clearly shown in Figure 7.10, the Railtrack plc operations has no direct interaction with contractors, nor is there an intervention of an audit system into contractors' operations. ExCo uses Key Indicators of Performance (KIP) to monitor contractor's performance through separate reports. Because of the split between the Railtrack plc operations and contractors, there is no clear co-ordination function between these two operations

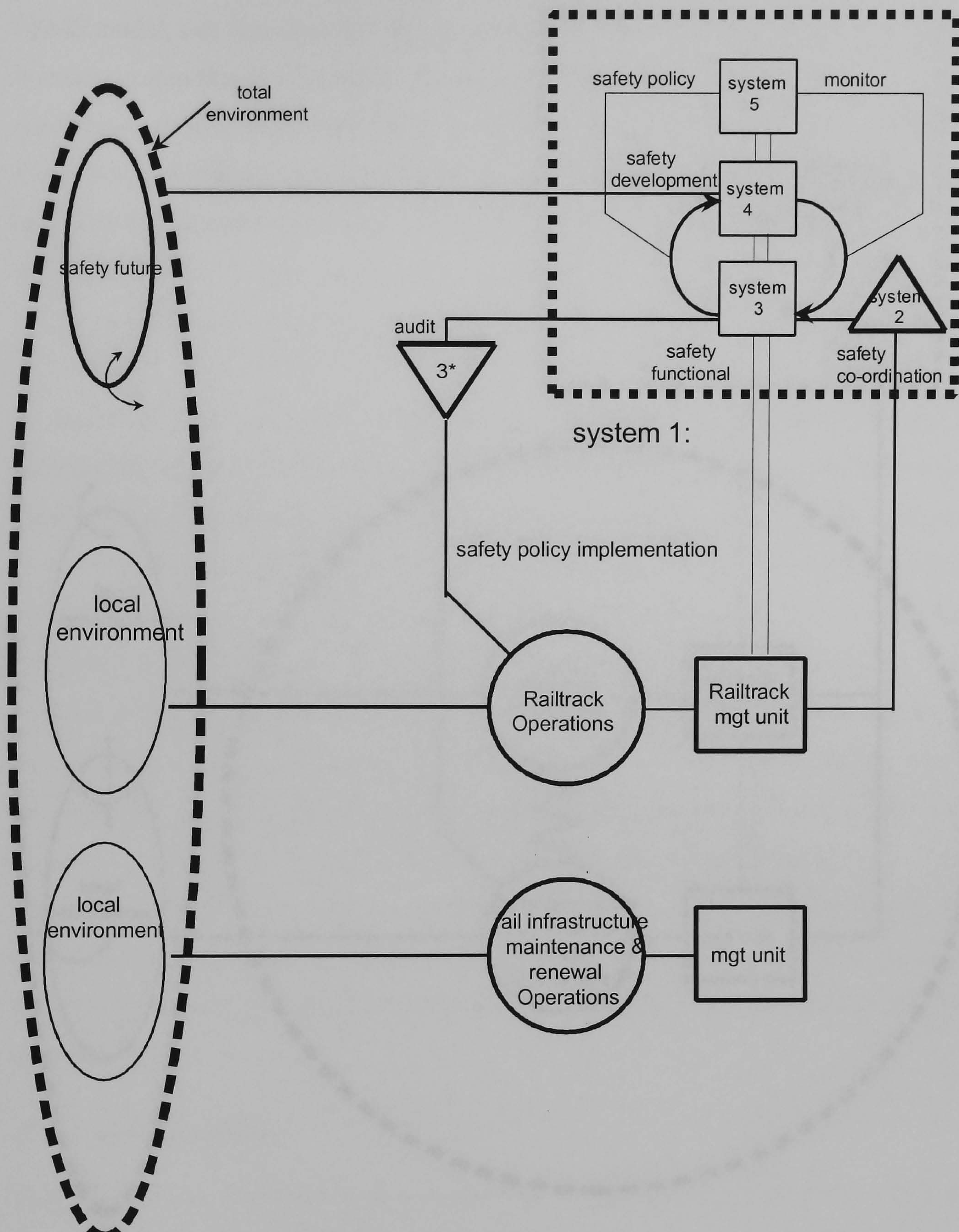


Figure 7.9 Railtrack Safety Management at Zone Level

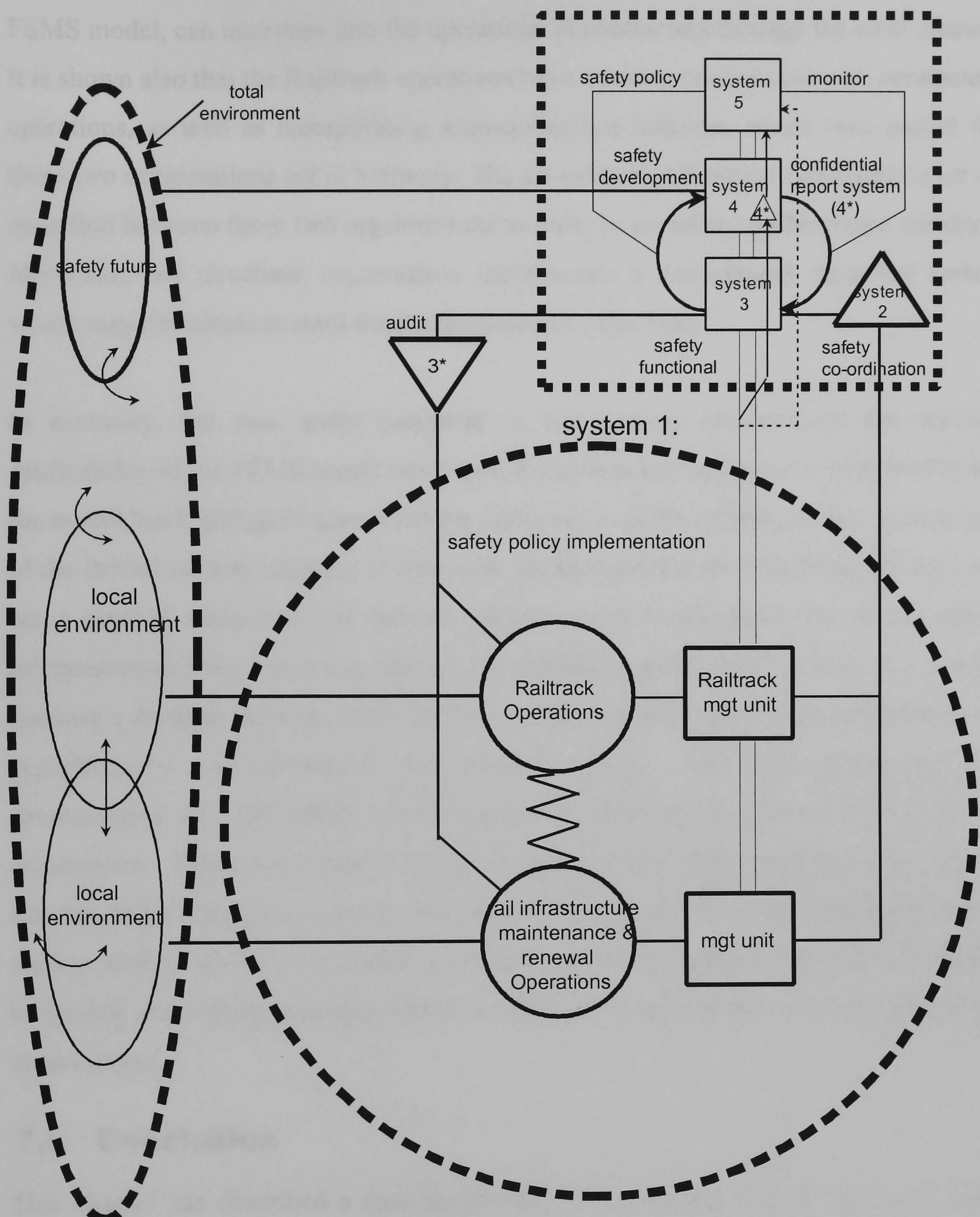


Figure 7.10 RSMS at Zone Level

Figure 7.10 illustrates a possible structural organisation that addresses these deficiencies. This structural organisation provides coherence to the operation of these two operations. The Railtrack's executive management, or systems 2 to 5 in terms of the FSMS model, can intervene into the operations of contractors through the audit channel. It is shown also that the Railtrack operations have a strong relationship with contractor's operations, as well as incorporating a co-ordination function, which may ensure that these two organisations act in harmony. The co-ordination function facilitates closer co-operation between these two organisations in order to set safety performance standards. Moreover, this structural organisation incorporates a confidential reporting system, which may contribute to meet the Railtrack safety objectives.

In summary, the case study presented in this section demonstrates the practical applicability of the FSMS model developed in this research project. As described above, the model has highlighted some relevant deficiencies of the existing safety management of the British railway industry. It should be emphasised that the researcher did not carry out a detailed analysis of the railway industry safety management due to the lack of information and the remaining time of the research project. Clearly, there is a need to conduct a detailed analysis of the railway industry to find out the effectiveness of the organisation's communication and control aspects. The case study has also demonstrated that the FSMS model can easily extended to address safety for any organisation. It has shown that the model could be used to understand not only a system that has failed, but also a system that has not failed yet. Moreover, the model can be used to address commercial aspects and safety considerations in a coherent way; that is, horizontal and vertical interdependence of the various operations that form part of any organisation.

7.5 Conclusion

This chapter has described a case study: that of the British railway industry's safety management. It first discussed the current state of the railway industry's safety management. It went on by presenting some relevant deficiencies of the existing railway industry's safety management in comparison with the FSMS model. Finally, it suggested an alternative systemic safety management system for the railway industry. Conclusions and implications are presented in chapter eight.

Chapter Eight

Conclusions and Implications

8.1 Introduction

Chapter one has described the motivation for this research project. It presented the research problem and put forward the research questions. The research methodology that was used to conduct and manage the research project was also described. Chapter two highlighted the need for an understanding of the systemic nature of fire safety in order to manage it in a coherent way. Chapter three described two systemic approaches, which have been used in the project. Chapters two and three concentrated on the theoretical foundations for approaching the research problem. These foundations helped to construct a prototype of the FSMS. The FSMS prototype was presented in chapter four. Chapter five presented the developed FSMS model. Chapter six discussed evaluation in relation to the FSMS model. A case study was conducted in order to assess the British railway safety management and it is presented in chapter seven. This final chapter gives an account of the learning experiences gained throughout the research project. Section 8.2 summarises the conclusions about the research questions. Conclusions about the research problem are presented in section 8.3. Possible implications of the FSMS model for Health, Safety and Environment Management systems and on Safety Management Systems are discussed in section 8.4. Conclusions about the FSMS model itself are presented in section 8.5. Section 8.6 highlights some possible implications of the research project for policy makers and practitioners. Section 8.7 discusses possible implications for future research. Finally, section 8.8 summarises this chapter.

8.2 Conclusions About the Research Questions

Three research questions were developed in the literature review of the research project, as discussed in chapter two, as a way of approaching the research problem, which was presented in section 1.2 of chapter one. This section presents findings in relation to these research questions.

For clarity, the research questions are presented again here:

- *What is a Fire Safety Management System?*
- *What defines an effective Fire Safety Management System so that it is capable of maintaining the operational safety of an organisation within an acceptable range?*
- *How can the fire safety performance of the Fire Safety Management System be measured?*

8.2.1 Defining the Fire Safety Management System

This section summarises the findings in relation to the research question: what is a Fire Safety Management System? Systems thinkers and practitioners have recognised that organisations are systems embedded within a broad context that cannot be treated in isolation. As discussed elsewhere[101,102,103,104], systemic thinking is holistic, involving seeing relationships amongst the parts that constitute an organisation, as well as the interaction between the organisation and its wider environment. It was argued in section 2.2 in chapter two that the distinction between systemic and reductionistic thinking is vital to the argument behind this research project. It seems that existing SMSs address fire safety within carefully set boundaries, which are assumed to isolate it from the wider or external environment. Both academe and practitioners tend to isolate fire safety events. This reductionistic view of fire safety is useful and necessary to understand fire risk, but isolating fire safety events may be insufficient to understand complex and unforeseen real-world fire safety situations. It is contended here that the degree of safety in an organisation or system is an emergent property resulting from the interrelated activities of people who design it, manage it, and operate it. All parts that constitute an organisation should be seen as interdependent and inseparable parts of the organisation as a whole. Moreover, these constituents are all interconnected, interrelated and interdependent so that they cannot be understood as isolated entities, but only as integrated parts of the organisation as a whole. Fire loss is therefore seen as a systemic failure, not a result of a single cause.

An FSMS can be defined as a systemic set of interrelated parts, which are arranged in a structured organisation; this arrangement of relationships serves a well-defined purpose. Additionally, a FSMS may be seen as complex, probabilistic, and self-regulated. The Fire Safety Management System, developed and proposed in this research project, is defined as a systemic set of five inter-related subsystems, called systems 1 to 5. These five subsystems are arranged in a structured organisation, which interacts in a defined way with its local and wider environment; both influencing it and being influenced by it. The organisation and the five subsystems of the FSMS are intended to maintain fire risk within an acceptable range in an organisation's operations life cycle. System 1, *fire safety policy implementation*, implements the organisation's fire safety policy. System 2, *fire safety co-ordination*, involves co-ordinating the various operations of system 1. System 3, *fire safety functional*, involves ensuring that the organisation's fire safety policy is implemented, as well as ensuring that the fire risk is maintained within an acceptable range. System 3*, *fire safety audit*, conducts sporadic audits into the operations of system 1. System 4, *fire safety development*, is responsible for the future fire safety development for the whole organisation. System 4*, *fire safety confidential reporting,* deals with the confidential fire safety information arising from system 1. Finally, system 5, *fire safety policy*, is responsible for establishing fire safety policies for the whole organisation.

By contrast, this definition does not agree with those presented in section 2.2 in chapter two. For example, in the Safety Case Regulations[42], a SMS is defined as those elements concerned with safety performance. Other researchers, such as Burkhardt[96], and Kandola[98], define a SMS in terms of hazard management, which includes hazard identification, risk assessment and control. SMSs are sometimes defined in terms of key elements, which are arranged in a systematic procedure rather than in a systemic structured organisation. Such definitions include those presented by the CCPS[113], HSE[119], Ming[94], and Mitchison and Papadakis[100]. Moreover, these SMSs are built on George[89] and Druker's[90] ideas of a management system. George defines key elements of management, namely planning, organising, commanding, co-ordinating, and controlling which are linked systematically to form a closed loop. Similarly, Druker contends that management involves setting objectives, organising, communicating, establishing yardsticks, and developing people. The FSMS model developed in this research project has some parallel elements with existing SMSs, as shown in the evaluation consideration of the FSMS model in section 6.3 in chapter six. The FSMS model is intended to be a viable system that achieves five interrelated functions associated with systems 1 to 5. Systems 1 to 5 and their relationships constitute the organisation of the FSMS model. Although existing SMSs have some parallel functions with the FSMS subsystems, the functions of these subsystems are fundamentally distinct. It seems that existing SMSs lack appropriate structured organisation that can help not only to give coherence to the SMS's key functions, but also to understand the interaction between the organisation and its environment. Moreover, existing SMSs, including the British railway safety management presented in chapter seven, seem to lack an effective structure that may help organisations to conduct decision making and communication, and instil an adequate safety culture. The FSMS contains a communication and control model that obeys the organisational principles of appendix A.

8.2.2 An Effective Fire Safety Management System

This section discusses the findings for the research question: what defines an effective Fire Safety Management System so that it is capable of maintaining the operational safety of an organisation? As has been discussed in section 2.2 in chapter two, there are no well-accepted criteria to define an effective SMS. It has been discussed by Grabowski and Roberts[12] that structure, safety culture, decision making, communication, and man-machine interface are key factors that have a significant impact on an organisation's safety performance. It has been recognised by researchers that a good communication system may help to instil and maintain an organisation's safety culture. It is also recognised elsewhere[77,78,79] that poor communication may be the result of lack of trust, and trust within organisations is a continuous process. Organisations should have a well-designed structure and strong safety culture to help to manage risk more effectively. Other researchers, such as Whittingham and Hollywell[95] , also recognise that effective safety management results from the combination of an SMS structure and the organisation's safety culture. Similarly the British Standard Institute (BSI)[58] emphasises that occupational health and safety policy, planning, implementation and operation, checking and corrective action, and management review are all essential for an effective OH&S management system. Travers[97] contends that the Successful Health and Safety Management (HS(G)65), provides the basic criteria for an effective management system. Reason[7] contends that an effective safety management means actively "navigating the safety space" in order to reach and then remain within the zone of "maximum resistance."

The comparison process presented in section 6.3 from chapter six, suggests that the FSMS model is an effective approach to managing fire safety. The structured organisation of the FSMS interacts in a defined way with its local and wider socio-economic and physical environment. This organisation may help to adapt continuously to foreseen and unforeseen threats and opportunities, and weaknesses and strengths as presented in the organisation's local and wider environment. Moreover, the organisation of the FSMS is intended to manage fire safety in a coherent way by treating an organisation as both vertically and horizontally interdependent. Vertical interdependence is dealt with through the recursive structural organisation of the FSMS. This favours autonomy, hence it helps to maintain an acceptable level of fire safety at each level of recursion more effectively. The horizontal interdependence is dealt with through the interrelationships amongst the various operations of the system. The channels that connect the different subsystems of the FSMS are channels of communication and control. These channels should be designed according to the four principles of organisation given in Appendix A. Additionally, the FSMS suggests a system for measuring continuously the organisation's fire safety performance. The structure of the FSMS, its relationship with its environment, and its channels of communication and control are the basic criteria that make the FSMS model an effective system in managing fire safety.

Besides this comparison process, a case study was conducted to assess the British railway safety management. The FSMS model highlighted some relevant deficiencies of the current practice. This case study also demonstrated that the FSMS model can also be adopted to address safety for any organisation.

Some relevant comments about the concept of a viable system and the principles of recursion should be made. Stafford Beer[81,82] defines viable as "able to maintain a separate existence". The principle of recursion states that any viable system contains, and is contained in, a viable system. Regarding human activity systems as viable systems, then it may be possible to construct a viable system with recursions at the level of an individual, family, company, country, and international level. Ostensibly, a viable system at the international level will be viable only if the next higher level of recursion is viable. However, there can be no human activity system 'above' the international community and therefore, it might be concluded that the principle of recursion must be violated and a FSMS could not, in principle, be viable. It may be the case, though, that a closed system may be viable and not need to be within a viable system. Such may be perhaps the case for the international community, given adequate material resources from outside the earth, e.g., the warmth of the sun. However, a hypothetical example could be if for any reason the sun ceased radiating heat, then the whole system at the level of the planet could no longer be viable in principle. These general considerations are open to further thought and discussion.

8.2.3 Measuring Fire Safety Performance

This section presents the findings for the last research question: how can the fire safety performance of the Fire Safety Management System be measured? Traditionally, measures of safety performance have tended to be reactive rather than pro-active. Organisations have tended to focus on technical aspects and look for the immediate causes of fire incidents or accidents after they have taken place. As discussed in section 2.5.1 from chapter two, organisations use reactive indicators, such as fatal accident rate, lost time injury rate, loss of containment rates, and other negative outcome indicators to measure the effectiveness of their safety management system[64,143,144]. The recommendations following an inquiry are seen as a readjustment process of the organisation's safety performance to fit the newly gained understanding. This allows the immediate causes that led to the failure to be learnt so that they are not repeated in future situations. More recently, various approaches have been suggested by both academe and practitioners to measuring safety performance pro-actively. Such approaches include the development of performance standards as discussed by Finucane[135] and the UKOOA[44]; the development of indicators for latent errors as proposed by Hudson et al.[19], and Reason[7]. Organisations have conducted safety audits,[137,100] guidelines[138,139], performance review and management review to 'validate' the effectiveness of their SMSs.

However, both academe and practitioners seem to pay very little attention to the underlying factors, such as latent and human factors. They have emphasised technical factors, and immediate causes of fire incidents or accidents. Furthermore, organisations may not address the revision of fire safety plans considering process changes, new technologies, and unforeseen causes of fire incidents during the life cycle of the organisation's operations. All these changes potentially invalidate prior fire safety plans. There is a need for an understanding of the systemic nature of fire safety so that both technical and human factors and the immediate and the underlying causes of fire incidents or accidents can be addressed in a coherent way. Moreover, an understanding of continuous decision making is needed to respond to unexpected changes or events to anticipate undesirable consequences for both fire safety and cost. This thesis presents an alternative system that may help to manage an organisation's fire safety performance. This approach may facilitate both understanding the systemic nature of fire safety and the distinction between acceptable and unacceptable fire risk levels. Furthermore, this understanding may enable organisations to commit to and address fire safety pro-actively.

As can be seen in Figure 5.2 from chapter 5, this system consists of four levels of fire safety, four kinds of fire safety plans, and four kinds of fire safety indices. These measures of fire safety performance can be used as a comprehensive system to measure an organisation's fire safety performance for all types of resources throughout the organisation. Moreover, the indices of fire safety performance presented in section 5.3.2 of chapter five are intended to contain both ECS and ICS, and to incorporate latent and immediate factors, as described in 5.3.2 in chapter five. The organisation's top and line management role in defining the fire safety levels, plans, and indices is threefold. First, they should define, in agreement with the organisation workforce, expected fire safety performance levels, develop fire safety plans and derive indices of performance. Second, top and line management should detect and if possible anticipate unacceptable fire safety performance before it becomes problematic. The current fire risk indices are compared with the planned indices. This process must be carried out continuously. Finally, they should devise actions to achieve agreed fire safety performance; that is, take actions that maintain fire safety performance within acceptable limits. A detailed description on how to carry out these three functions is given in section 5.3.2 from chapter five.

8.3 Conclusions About the Research Problem

This section summarises the findings of this research project for the research problem: what does an organisation need to do to anticipate fire risks so that fire risk can be maintained within an acceptable range throughout the organisation's operational life cycle? This research project contends that a systemic approach needs to be adopted to address fire safety in a coherent way. The FSMS model is a systemic set of five necessary and sufficient subsystems associated with systems 1 to 5, which are arranged in a structured organisation. The organisation of the FSMS model interacts with its local and wider socio-economic and physical environment. Moreover, this organisation is intended to help to manage fire safety effectively through the vertical and horizontal cohesiveness of the FSMS. The vertical interdependence deals with the recursive property of the structural organisation of the FSMS, whilst the horizontal interdependence deals with the interrelationship amongst the various operations that form part of system 1. An organisation should be endowed with as much autonomy as possible in order to accomplish the fire safety objectives more effectively. The principle of recursion should be adhere to.

Also, the channels of communication and control of the FSMS model should be designed according to the four organisational principles, which help to make the FSMS an effective approach to managing fire safety. Furthermore, the FSMS model contains a system that is intended to measure the fire safety performance of the FSMS; this system considers both ICS and ECS for both apparent and latent factors. Additionally, a fire safety configuration space is suggested in chapter five. This framework may help to distinguish the notion of acceptable and unacceptable levels of fire safety. The FSMS model is an effective approach, because it embodies the idea of a viable system, a structural organisation, which is formed by the subsystems and their relationships, vertical and horizontal cohesiveness of the organisation, the principle of autonomy, and the organisational principles to design channels of communication and control. As shown in the evaluation considerations in section 6.3 from chapter six, the existing SMSs, including the case study presented in chapter seven, are systematic procedures rather than systemic structural organisations. It is hoped that this approach will lead not only to more effective management of fire safety in organisations, but also to more effective management of safety, health and the environment for any organisation.

8.4 Implications for Health, Safety and the Environment

This section summarises the findings of this research project that may have some implications for Health, Safety and the Environment. As can be seen in tables 6.1, 6.2, 6.3, 6.4, 6.5 and 7.1, the existing systems for managing health and safety and environmental impacts approach matters in isolation. It is contended in this thesis that the degree of health and safety and environmental degradation are all emergent properties of an organisation as a whole that emerge throughout the organisation's life cycle. There is a need to adopt a systemic approach that can help organisations to manage health, safety and environmental issues effectively. Because of the scope and limitations of this research project, the FSMS model reported in this thesis was developed to address fire safety. However, this model was used to address safety in the British railway industry as described in chapter seven. Similarly, this model may be extended to address health, safety and environmental concerns. Clearly, this will require further research, as discussed in section 8.7.

8.5 Conclusions About the Use of the FSMS

The development of the FSMS model has been a continuous process, as illustrated in Figure 8.1. A first prototype of the FSMS was established initially; chapter four gives an account of the development of this prototype. The FSMS prototype was mapped to the Fortune and Peters paradigms as discussed in section 4.4 from chapter four. A final FSMS model resulted from this mapping process. The FSMS model was presented in chapter five and its evaluation process described in chapter six. According to the mappings discussed in section 6.3 from chapter six and the case study presented in chapter seven, the FSMS may help to manage not only fire safety more effectively, but also to manage health, safety and the environment and for any organisation. Clearly, this requires the FSMS to be further developed; these requirements are discussed in section 8.7.

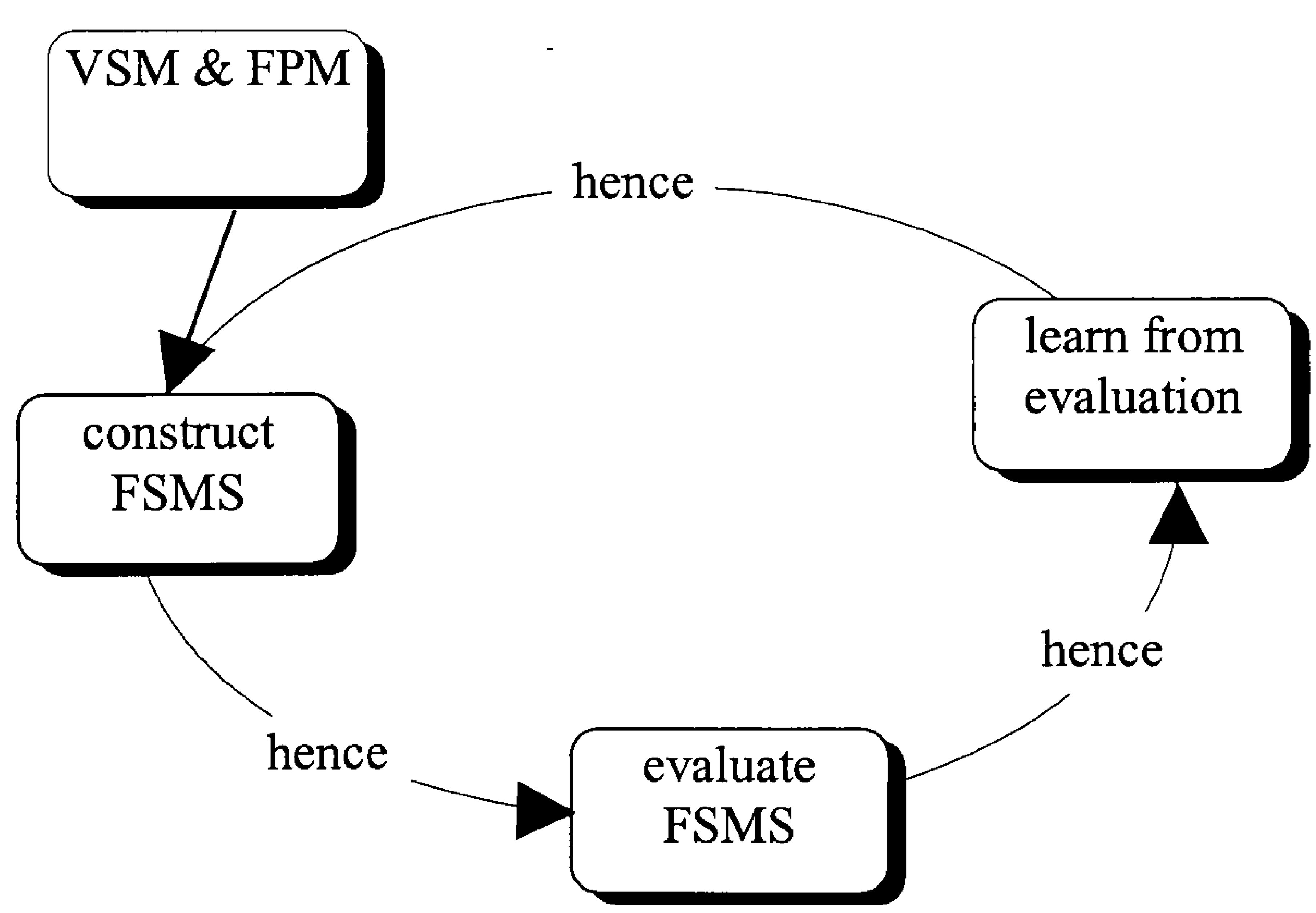


Figure 8.1 A Continuous Development Process of the FSMS Model

8.6 Implications for Policy and Practice

This section presents possible implications of this research project for policy makers and practitioners. The FSMS model has a recursive structural organisation, which favours autonomy at each level of recursion. But this autonomy is conditional on the cohesiveness of the whole organisation. Autonomy means that each operation of system 1 or each level of recursion of the FSMS is responsible for its own activity with minimal intervention of systems 2, 3, 4, and 5. Similarly, if higher recursions are considered, policy makers should endow organisations with as much autonomy as possible to make them more effective. Organisations should be autonomous in their own right and act independently based on their own understanding of fire safety and their specific operations. It should, however, be recognised that policy makers should intervene in an organisation to ensure that their safety objectives are being met. However, a system will not be viable unless it is embedded within a viable system and contains viable systems. As discussed in the evaluation consideration in section 6.3 from chapter six and the case study presented in chapter seven, the FSMS is a systemic model that can be adopted by both practitioners and policy makers to assess existing SMSs. Moreover, this model can be used to develop effective SH&E Management Systems.

8.7 Implications for Future Research

Future research is categorised into three major activities:

(i) Extension of the FSMS model to address safety, health and the environment and ultimately to sustainable development. This new model should be sufficiently general to be used in any kind of organisation. The process should also involve mapping the new model to existing HS&E Management Systems.

(ii) Calculation of the viability of the FSMS model as a whole, as discussed in section 6.4 from chapter six.

(iii) Ultimately, real-world uptake of the FSMS model should enable testing of the model 'in the field'.

(iv) The "fire safety configuration space" may be thought of in terms of fuzzy set theory, which will need further research to consolidate the idea.

8.8 Conclusion

This chapter has summarised the conclusions about the research questions and the research problem. It has proceeded by presenting the implications of the research project for health, safety and the environment. Conclusions about the use of the FSMS model have been presented. Possible implications for policy-makers and practitioners have also been presented. Finally, this chapter has concluded by giving some implications for future research. The remaining sections of this thesis are concerned with appendices and references.

Appendix A

Principles of Organisation (from Beer [82])

The first Principle of Organisation (from Ashby Law, see chapter 3, page 51)

"Managerial, operational and environmental varieties, diffusing through an institutional system, tend to equate; they should be designed to do so with minimum damage to people and to cost." (i.e., for a viable system).

An example could be an evacuation system designed to save lives in the case of a fire or explosion on an offshore platform; then the number of life boat spaces must be at least as great as the number of possible evacuees.

The Second Principle of Organisation (derived from Shannon)

"The four directional channels carrying information between the management unit, the operation, and the environment must each have higher capacity to transmit a given amount of information relevant to variety selection in a given time than the originating subsystem has to generate it in that time." (As shown in Figure A1).

Example, the channels carrying procedures of evacuation must have enough specificity so as to reduce ambiguities or eliminate unclear instructions.

The third Principle of organisation

"Wherever the information carried on a channel capable of distinguishing a given variety crosses a boundary, it undergoes transduction; and the variety of the transducer must be at least equivalent to the variety of the channel."

Example, in the case of means of escape for offshore employees, a transducer might be a fire instruction notice. This would 'transduce' between the person making up the evacuation rules and the workers the rules are aimed; then the notice must be comprehensive and clear.

The Fourth Principle of Organisation

"The operation of the first three principles must be cyclically maintained through time, and without hiatus or lags." (That is, they must be adhered to continuously).

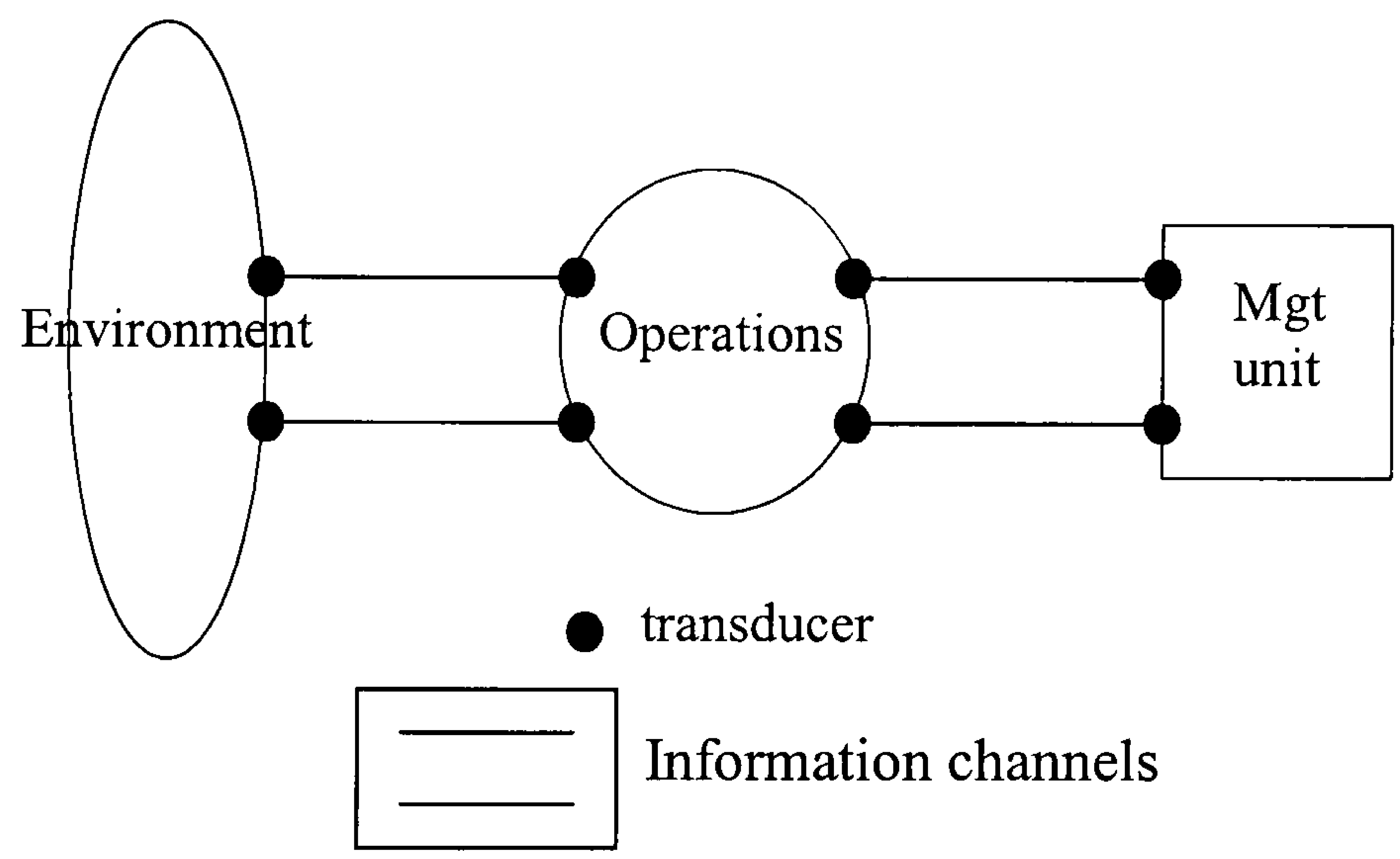


Figure A1. The Basic Elements of a Viable System, Illustrating the 4 Key Information Channels.

Appendix B

This appendix presents the research articles produced during this work.

Refereed journal papers:

1. Beard A. N. and Santos-Reyes, J., "A Systemic Approach to Fire Safety in Offshore Facilities", *Facilities,* Volume 17, No. 9/10, September / October 1999, 352-361.
2. Santos-Reyes, J., Beard A. N. and Clark, P. J., "A Systemic Approach to Fire Safety Offshore", *Journal of Applied Fire Science,* Volume 8, No. 12, 1998-99.

Conference papers presented:

1. Santos-Reyes, J., Beard A. N. and Clark, P. J., "A Systemic Approach to Fire safety Offshore", *Proceedings of the International Conference - Fire at Sea, Royal Inst. Of Naval Architects (RINA),* London, 1997.
2. Santos-Reyes, J., Beard A. N., "A Systemic Approach to Managing Fire Safety on Offshore Installations", *Proceedings of the Offshore Technology Conference (OTC)-Where the World of Offshore Technology Meets,* Vol. 1, 2000, 689-697.

Refereed Journal paper accepted:

1. Santos-Reyes, J., Beard, "A Systemic Approach to Fire Safety Management", *Fire Safety Journal,* (to be published).

Newsletter:

1. Santos-Reyes, J. and Beard, A. N., "A Systemic Approach to Offshore Fire Safety Management", *FABIG (Fire and Blast Information Group) Newsletter,* Issue No. 24, June 1999, 11-14.

Papers in preparation:

1. Santos-Reyes, J., Beard A. N., "A Systemic Approach to Measuring Fire Safety Performance", to be submitted to the *Journal of Fire Science.*
2. Santos-Reyes, J., Beard A. N., "A FSMS Model: Assessing Safety Management Systems", to be submitted to the *Journal of Loss Prevention.*
3. Santos-Reyes, J., Beard A. N., "A Fire Safety Management System: A Viable System", to be submitted to the *Journal of Systemic Practice and Action Research.*

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